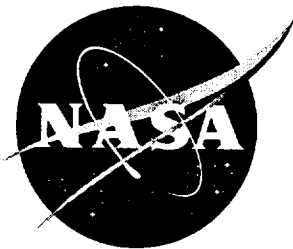


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A Revised Thermosphere for the Mars Global Reference Atmospheric Model (Mars-GRAM Version 3.4)

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Preface

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1. Background

The Mars Global Reference Atmospheric Model (Mars-GRAM) was developed (Johnson et al., 1989; Justus 1990, 1991) as an engineering-oriented, empirical model of the Mars atmosphere. A complete history and description of the model, through version 3.34, was recently given in the Mars-GRAM programmer's guide (Justus et al., 1996). Mars-GRAM is based on surface and atmospheric temperature data observed during the Mariner (orbiter) and Viking (orbiter and lander) missions and on surface pressure data observed by the Viking landers. At the higher altitudes (above about 120 km), Mars-GRAM (through version 3.34) was based on the Stewart (1987) model for the global-mean thermosphere.

Mars-GRAM provides both mean and mountain-wave perturbed atmospheric density for any location (height, latitude, and longitude) and time (seasonal and diurnal). Other atmospheric variables provided include atmospheric temperature, pressure, and wind components. Dust storm effects are included for all atmospheric parameters controlled by user-selected options. The model also includes the option to simulate either local-scale or global-scale dust storms and density perturbations from tidal waves, computed by the Zurek wave model, Pitts et al. (1990?). Other recent features include (1) a limitation, based on atmospheric stability considerations, for the magnitude of the mountain-wave density perturbations, (2) comparisons of density, temperature, and pressure with the COSPAR reference atmosphere (Pitts et al., 1990?), and (3) a new method for estimating the diurnal range of the surface temperature based on the diurnal variability of the surface-absorbed solar energy. Technical descriptions of all these features are given in the programmer's guide (Justus et al., 1996).

The original Stewart (1987) thermospheric model, designed to estimate global mean conditions only, has two major shortcomings for use as the thermospheric portion of Mars-GRAM: (1) does not produce realistic variations of temperature and density with latitude and time of day (or longitude), (2) is not capable of providing realistic horizontal gradients of pressure, from which thermospheric winds are estimated. The additions to Mars-GRAM discussed here are designed to overcome these deficiencies.

Mars-GRAM was developed from parameterizations to atmospheric data observed by the Mariner (orbiter) and Viking (orbiter and lander) missions and thus, is representative of the Mars atmosphere during the 1970's. Recent observations by Clancy et al. (1990) indicate that, in response to atmospheric cooling as the dusty atmosphere has cleared in the last two decades, current Mars temperature profiles are distinctly cooler than those observed in the Viking era. Comparisons of Mars-GRAM 3.34 mid-latitude average temperature profiles with recent data from Clancy (provided by Rich Zurek, private communication), indicate about 20 K cooling in the 40-50 km height range, about 15 K at 20-30 km, but little change in the 5-10 km region. This temperature change could have significant effects on atmospheric density at high altitudes and, as pointed out by Clancy et al. (1990), is quite important in planning for Mars missions that involve aerobraking.

To accommodate these possible effects of climate shifts, Mars-GRAM version 3.4 allows the user to select climate modification factors for the temperature profile between the surface and 75 km. Additionally, the user may adjust at run time relevant values of the global

mean thermosphere (exospheric temperature, and temperature and height of the base of the thermosphere).

Proper computations of variation with time of day depend on accurate estimates of longitude of the sub-solar point on the surface of Mars. In the original (1989) development of Mars-GRAM an empirical fit for sub-solar longitude versus time was derived from Mars ephemeris data for 1984 through 1988. This empirical fit was incorporated into the "ORBIT" subroutine. The original ORBIT subroutine used a time variation for sub-solar longitude based on a Fourier harmonic series with a basic period of 696 days. For Mars-GRAM version 3.4, we obtained (Myles Standish, Jet Propulsion Laboratory, private communication) a set of Mars ephemeris data from 1984 through 2003. A Fourier fit with this longer time series revealed that the sub-solar longitude was reproduced significantly better with two harmonic series, one with the basic period of the Mars orbit (687 days) and another with 777 days. This new, dual-period parameterization was incorporated into the ORBIT subroutine of Mars-GRAM 3.4.

2. Methods for Thermospheric Calculations

2.1 Overview of Thermospheric Model Methods

Five basic parameters are used to prescribe the height variation of pressure, density, and temperature in the Stewart (1987) thermospheric model: (1) pressure (PRESSF) at base of the thermosphere, assumed to be the fixed value 1.26 nanobars ($1.26 \times 10^{-4} \text{ N/m}^2$), (2) height (ZF) of base of the thermosphere, (3) temperature (TF) of base of the thermosphere, (4) exospheric temperature (TINF), and (5) a parameter (SCALE) that describes the height variation of temperature between base of the thermosphere and the exosphere. In the original Stewart thermospheric model, ZF, TF, TINF and SCALE are considered global average values dependent on either the 10.7-cm solar flux (F10.7) or the heliocentric distance of Mars from the Sun, in Astronomical Units (RAU). In the new thermospheric model, these parameters are also functions of latitude and time of day (longitude). Details of computation of the height variation of temperature, pressure, and density are identical to the original Stewart thermospheric model.

For an altitude (Z) above the base of the thermosphere of $ZZF = Z - ZF$, located where the radius of the Mars reference ellipsoid is $R0$ (and $RF = R0 + ZF$), the vertical temperature variation is computed by

$$\begin{aligned} YSC &= ZZF * RF / (RF + ZZF) & \text{THRM108} \\ TZ &= TINF - (TINF - TF) * \exp(-YSC / SCALE) & \text{THRM109} \end{aligned}$$

(Letters and number at the right are line numbers of the FORTRAN source code of the Mars-GRAM program.) Scale height (HH) and partial pressure (PRZ) for each thermospheric constituent are computed by

$$\begin{aligned} HH(I) &= BK * TINF / (GF * DM(I)) / 1.0E5 & \text{THRM111} \\ PRZ(I) &= PRESSF * FF(I) * \exp(-YSC / HH(I) - (SCALE / HH(I)) * \text{ALOG}(TZ / TF)) & \text{THRM113} \end{aligned}$$

where FF is a fractional composition for each constituent. This fairly simple analytical expression for pressure variation can be used because the particular functional form assumed for temperature variation (code line THRM109) yields a closed-form solution for the vertical integral of the hydrostatic equation. Note that the decrease of gravity with height (inversely proportional to the square of radial distance) is explicitly accounted for in this hydrostatic integral solution (code line THRM113).

Density is computed from the total pressure (sum of the partial pressures) and temperature, using the perfect gas law relation. The problem of specifying temperature, pressure, and density at any height, latitude, time of day, time of year, and solar activity condition, becomes specifying dependence of ZF, TF, TINF, and SCALE on these factors.

2.2 Dependence on Heliocentric Distance and Solar Activity

A collection of thermospheric parameter estimates, observations and model results, is assembled in table 2.1. The data were collected and given in model results or measurement-model comparisons by Bougher et al. (1988, 1990, 1993) and Bougher (1995). All parameter values in table 2.1 are global mean conditions.

Table 2.1. Global mean values of thermospheric parameters from various measurements or model results [Bougher et al. (1988, 1990, 1993) and Bougher (1995)]. R is the heliocentric distance of Mars, TINF is exospheric temperature, TF and ZF are (respectively) the temperature and height of the base of the thermosphere, and SCALE is the height variation parameter for thermospheric temperature.

Data Source	R (AU)	10.7-cm Solar Flux		TINF (K)	TF (K)	ZF (km)	SCALE (km)
		1 AU	Mars				
Mariner 4	1.55	77	32			117	
Mariner 6-7	1.45	206	98	240	170	129	
Mariner 9 (primary)	1.48	110	50	220	160	123	
Mariner 9 (extended)	1.62	115	44			115	
Viking Lander 1	1.62	68	26	180	125	125	
Viking Lander 2	1.63	74	28	180	125	121	
Phobos (DMED)	1.53	150	64	215		125	
Phobos (DMAX)	1.67	150	54	200		115	
Phobos (DMIN)	1.38	150	79	230		135	
MTGCM, MGS97L	1.38	130	68	228	147	128	15.0
MTGCM, MGS98L	1.66	130	47	196	141	115	12.9
MTGCM, MANC00	1.53	150	64	229	147	122	14.6
MTGCM, MGS97T	1.40	80	41	185	139	127	12.4

Regression relations versus both heliocentric distance (R) and 10.7 cm solar flux at Mars (F10.7) were tested. The resulting best fit relationships to describe the variation of the global mean thermospheric parameters are the following:

$$\langle TINF \rangle = 156.3 + 0.9427 F10.7 \quad (2.1)$$

$$\langle ZF \rangle = 197.94 - 49.058 R \quad (2.2)$$

$$\langle TF \rangle = 113.7 + 0.5791 F10.7 \quad (2.3)$$

$$\langle SCALE \rangle = 8.38 + 0.09725 F10.7 \quad (2.4)$$

where the angle brackets denote global average values.

Figures 2.1 through 2.4 illustrate the regression relations (2.1) through (2.4) versus data from table 2.1. The example point (labeled VL-1) in each figure is the data point for the Viking 1 Lander (VL-1) case. The figures show the VL-1 point is reproduced fairly well for $\langle T_{INF} \rangle$ and $\langle T_F \rangle$ regressions, but the VL-1 point is a significant "outlier" in the $\langle Z_F \rangle$ regression. Thus, in order for the model to reproduce specific cases, it may be necessary for the user to adjust the regression values by appropriate amounts (e.g., an increase of about 8 km in $\langle Z_F \rangle$ to replicate the VL-1 case). Note that the VL-1 case was also a significant outlier in the regression plot Stewart (1987) derived for ZF versus heliocentric distance (from which he derived a $1/R$ regression relation for ZF). The user-input adjustment parameters (ΔT_{EX} for exospheric temperature, and ΔT_F and ΔZ_F for temperature and height of the base of the thermosphere) are discussed more fully below and in Appendix A.

The regression relation for global mean exospheric temperature [equation (2.1) and figure 2.1] gives exospheric temperatures significantly lower than the original Stewart regression. However, the new exospheric temperature regression is quite similar to the curve described by the lower boundary of the shaded portion of figure 9 of Bougher et al. (1990), which also applies to global mean exospheric temperature. [The middle and upper curves within the shaded area of Bougher's figure 9 are for mid-afternoon and dayside-mean exospheric temperatures, not global mean values.] Note that equation (2.3) implies a dependence of T_F on solar activity ($F_{10.7}$), rather than an orbital radius (R), as assumed by Stewart. Residual error from regression via equation (2.3) is 8.1 K (essentially the same as residual error from multiple regression against both $F_{10.7}$ and R). Residual error from regression against R alone (yielding $\langle T_F \rangle = 267.13 - 80.905 R$) is 13.9 K. The physical reality of the dependence of T_F on $F_{10.7}$, implied by equation (2.3), is still being evaluated.

2.3 Dependence on Latitude, Sub-Solar Latitude, and Time of Day

Four sets of output from the Mars Thermospheric Global Circulation Model (MTGCM, Bougher et al., 1990) were used to derive the dependence of the thermospheric parameters on latitude, sub-solar latitude, and time of day. Parameterization relations for the various thermospheric parameters were derived and incorporated into a new subroutine (Thermpar, line numbers denoted TPAR, see Appendix A). The four MTGCM cases used were "MGS97L", "MGS98L", "MANC00" and "MGS97T"; characteristics are given in table 2.1.

In the subroutine Thermpar, the local (latitude and time of day dependent) value of exospheric temperature (T_{INF0} , K) is computed from the global average value ($\langle T_{INF} \rangle = T_{bar}$) by the program steps:

C...	Zonal average exospheric temperature (K) versus latitude	TPAR 47
	$T_{avg} = T_{bar} * (1. + 1.369E-4 * sunlat * lat)$	TPAR 48
C...	Phase angles (hours) for local solar time variation	TPAR 49
	$t1 = 13.2 - 0.00119 * sunlat * lat$	TPAR 50
	$t2 = 9.4 - 0.00231 * sunlat * lat$	TPAR 51
C...	Amplitude factor for local solar time variation	TPAR 52
	$cphi = \cos(\pi/180 * (lat + sunlat) / (1. + LATMAX/90.))$	TPAR 53
C...	Exospheric temperature (K) versus local solar time	TPAR 54
	$T_{INF0} = T_{avg} * (1. + 0.22 * cphi * \cos(\pi/180 * 15.0 * (LST - t1))) +$	TPAR 55
	$\& 0.04 * cphi * \cos(\pi/180 * 30.0 * (LST - t2)))$	TPAR 56

where "lat" is the local latitude (in degrees), "sunlat" is the latitude (in degrees) of the sub-solar point on the Mars surface, and "LST" is the local Mars solar time (in Mars hours = 1/24th sol).

Local height of the base of the thermosphere (ZF0 in km) is computed from the global average value ($\langle ZF \rangle = Zbar$) by program steps:

```

C... Latitude variation factor                                TPAR 59
factlat = (sunlat/LATMAX)*(lat/77.5)**3                      TPAR 60
C... Zonal average base height (km) versus latitude          TPAR 61
Zavg = Zbar + 4.3*factlat                                     TPAR 62
C... Amplitudes for local solar time variation                TPAR 63
A1 = 1.5 - Cos(pi180*4.0*lat)                                TPAR 64
A2 = 2.3*(Cos(pi180*(lat + 0.5*sunlat)))*3                   TPAR 65
C... Phase angles (hours) for local solar time variation      TPAR 66
t1 = 16.2 - (sunlat/LATMAX)*Atan(pi180*10.0*lat)              TPAR 67
t2 = 11.5                                                       TPAR 68
C... Base height of thermosphere (km) versus local solar time TPAR 69
ZF0 = Zavg + A1*Cos(pi180*15.0*(LST-t1)) +                    TPAR 70
& A2*Cos(pi180*30.0*(LST-t2))                                  TPAR 71

```

Local temperature (TF0, K) at the base height of the thermosphere is computed from its global average value ($\langle TF \rangle = Tbar$), by subroutine steps:

```

C... Zonal average temperature at thermosphere base (K) vs. latitude TPAR 74
Tavg = Tbar*(1. + 0.186*factlat)                               TPAR 75
C... Amplitudes for local solar time variation                TPAR 76
A1 = 0.06 - 0.05*Cos(pi180*4.0*lat)                            TPAR 77
A2 = 0.1*(Cos(pi180*(lat + 0.5*sunlat)))*3                     TPAR 78
C... Phase angles (hours) for local solar time variation      TPAR 79
t1 = 17.5 - 2.5*(sunlat/LATMAX)*Atan(pi180*10.0*lat)           TPAR 80
t2 = 10.0 + 2.0*(lat/77.5)**2                                   TPAR 81
C... Thermosphere base temperature (K) versus local solar time TPAR 82
TF0 = Tavg*(1.0 + A1*Cos(pi180*15.0*(LST-t1)) +                TPAR 83
& A2*Cos(pi180*30.0*(LST-t2)))                                  TPAR 84

```

The SCALE parameter does not depend significantly on time of day, so the global average value is simply adjusted for latitude dependence by program step:

```

C... Zonal average temperature scale height (km) vs. latitude TPAR 87
SCALE = SCALE*(1.14 - 0.18*Cos(pi180*lat))                     TPAR 88

```

Following computation of the local (latitude and time-of-day-dependent) thermospheric parameters by subroutine Thermpar, the values are adjusted for long-term and short-term variability via the "ES" array of the Stewart model for the effects of seasonal variations in surface pressure ("DR"), the effects of dust storms ("DUST"), and the user-selected adjustment parameters ("deltaZF" for the height of the base of the thermosphere, "deltaTEX" for exospheric temperature, and "deltaTF" for temperature at the base of the thermosphere). The adjustments are accomplished in the "STEWART2" subroutine as follows:

```

ZF = ZF0 * EXP(ES(8) + ES(9)) + DR + DUST + deltaZF          STW2 38
TINF = TINF0 * EXP(ES(2) + ES(3)) + deltaTEX                  STW2 46
TF = TF0 * EXP(ES(8) + ES(9)) + deltaTF                        STW2 47

```

The two ways to adjust thermospheric values are: (1) through input of "STDL", which controls the long-term variability by the Stewart ES parameters [ES(2) for TINF and ES(8) for ZF and TF], see section 6, and (2) through input of adjustment parameters deltaZF, deltaTEX, and deltaTF, see section 6. Short-term variability by the Stewart ES parameters [ES(3) for TINF and ES(9) for ZF and TF] are set automatically in the program, during computation of the high and low density perturbation magnitudes.

2.4 Revised Thermospheric Wind Calculations

Wind components in the Mars-GRAM thermospheric height region are computed as follows:

```

VISCFAC = 0.04*VISC/(1.0E6*DENS*VLL**2)                      DSTP134a
DENOM = CORIOL**2 + VISCFAC**2                                DSTP158
C... Viscous-corrected areostrophic wind components           DSTP159
EWWIND = (CORIOL*FUG - VISCFAC*FVG)/DENOM                     DSTP160
NSWIND = (CORIOL*FVG + VISCFAC*FUG)/DENOM                     DSTP161

```

where "VISC" is the coefficient of molecular viscosity, "DENS" is the atmospheric density, "VLL" is a vertical scale parameter, and "CORIOL" is the coriolis factor. At lower altitudes, where the viscosity effect is small, the eastward (northward) wind component ("EWWIND" or "NSWIND") becomes equal to the eastward (northward) areostrophic wind (on Earth called the geostrophic wind) component ("FUG" or "FVG"). The areostrophic wind blows parallel to isobars (lines of constant pressure). At higher altitudes, where the viscosity effect becomes dominant, the winds take on a significant cross-isobar component, with the viscous-corrected wind blowing perpendicular to the isobars (toward the low pressure side). In the thermosphere, isotherms (lines of constant temperature) tend to align somewhat with the isobars. Therefore, the viscous wind model above has significant components along the isotherms at lower thermospheric altitudes and significant cross-isotherm components at higher altitudes.

The only change in the viscous wind model for Mars-GRAM version 3.4 was to reduce the coefficient (line DSTP134a) from 1 to 0.04. In the original Stewart model, the pressure had extremely weak horizontal gradients (yielding weak areostrophic wind component estimates). With the realistic latitude-longitude variability for pressure that is now incorporated into the Mars-GRAM 3.4 thermospheric model, pressure gradients (and areostrophic winds) are much larger in the thermosphere and require the smaller coefficient on the viscosity term. The value of 0.04 was derived to reproduce as closely as possible the wind

data in the four MTGCM cases used to derive the parameterizations for the other thermospheric variables.

3. Results from the New Thermospheric Model

Figures 3.1 and 3.2 compare plots of exospheric temperature versus latitude and time of day from the Mars Thermospheric Circulation Global Model (MTGCM) case MGS98L (see table 2.1 for characteristics of the model cases) with similar estimates from the new Mars-GRAM thermospheric model. Figures 3.3 and 3.4 show analogous comparisons between MTGCM case MGS97L and Mars-GRAM thermospheric temperatures.

Figure 3.4 also illustrates the wind vectors from the new thermospheric model and shows the expected strong cross-isotherm components, discussed in Section 2.4. Strong cross-isotherm components are also a feature of the upper levels of the MTGCM output (e.g. Bougher et al., 1990, figure 7a; Bougher et al., 1993, figure 4a).

Figures 3.5 and 3.6 illustrate the latitude versus time of day dependence of atmospheric density at a height intermediate between the base of the thermosphere and the exosphere (180 km), for the MTGCM case MGS98L. Figures 3.7 and 3.8 are comparable plots for MTGCM case MGS97L and Mars-GRAM new thermospheric model.

Figure 3.9 shows the MTGCM case MGS98L values of temperature (TF) at the base of the thermosphere versus latitude and time of day. Figure 3.10 is a plot from Mars-GRAM for temperature at a height of 130 km (near the base of the thermosphere) and for the time corresponding to the MGS97L case. Figure 3.10 also shows the wind components derived from Mars-GRAM, and illustrates the expected significant along-isotherm components. Figure 3.11 illustrates the latitude and time of day dependence for the height of the base of the thermosphere (ZF) for MTGCM case MGS97L.

Characteristics of the new thermospheric model in Mars-GRAM are to have a predominant wave-one (one wavelength per 360 degrees of longitude) component for exospheric temperature, but a predominant wave-two component, especially at low latitudes, for the temperature and height of the base of the thermosphere. These features can be seen as general characteristics of the MTGCM data (in figures 3.1, 3.3, 3.5, 3.9 and 3.11). Although Mars-GRAM cannot reproduce the effects of components with wave numbers higher than two, the effects are evident in the MTGCM results. General features of latitude versus time of day variation of the MTGCM results are considered to be adequately represented by the new Mars-GRAM thermospheric model.

Figures 3.12 and 3.13 compare the height versus time of day behavior for MTGCM case MGS97L and Mars-GRAM. The general structure of the MTGCM results is reproduced in the Mars-GRAM plot.

4. The New Sub-Solar Longitude Model

Regular publication of latitude and longitude of the sub-solar point on the Mars surface began in 1984. Consequently, when Mars-GRAM was originally developed in 1989, the time series of longitude for the sub-solar point on Mars was limited to the time period 1984-1988. Mars ephemeris data are now available in computer-readable form from the Jet Propulsion Laboratory (JPL). The available data include not only prior time periods, but also projections for a number of years into the future. A set on Mars longitudes for the sub-solar point for 1984 through 2003 was constructed by making use of this JPL data (sent to us via electronic file transfer by Myles Standish of JPL).

From the limited (1984 to 1988) time series, it was apparent that the sub-solar longitude has a significant contribution from periods longer than the Mars orbit period (687 days). An empirical Fourier harmonic fit (with three harmonic terms) and a basic period of 696 days was used in the original Mars-GRAM version. This procedure is retained through Mars-GRAM version 3.34. However, it was recently noticed (Penny Niles, Lockheed Martin) that for the years near the end of this century, the sub-solar longitude values from Mars-GRAM could be in error by several degrees.

With the longer time series (1984 to 2003) a new harmonic fit showed that the sub-solar longitude variations are much better reproduced by a (three harmonic) Fourier series with two basic periods. The two periods in the new parameterization are 687 days (the fundamental period of the Mars orbit) and 777 days. The new relations reproduce sub-solar longitude values within a few tenths of a degree over the data series. This accuracy is comparable to frequently-used methods to compute the solar position from Earth using the day of the year as input. For leap year versus non-leap year variations, methods using day of the year input are accurate to a few tenths of a degree.

Details of the new calculations for sub-solar longitude are seen in program changes for the ORBIT subroutine in Appendix A.

5. New Climate Adjustment Parameters

Mars-GRAM was developed from parameterizations to atmospheric data observed by the Mariner (orbiter) and Viking (orbiter and lander) missions and represented the Mars atmosphere during the 1970's. Recent observations by Clancy et al. (1990) indicate, in response to atmospheric cooling as the dusty atmosphere has cleared in the last two decades, that current Mars temperature profiles are distinctly cooler than those observed in the Viking era. Comparisons between Mars-GRAM 3.34 mid-latitude average temperature profiles with recent data from Clancy (provided by Rich Zurek, private communication), indicate about 20 K cooling in the 40-50 km height range, about 15 K at 20-30 km, but little change in the 5-10 km altitude region. This temperature change could have significant effects on atmospheric density at high altitudes, and, as pointed out by Clancy et al. (1990), is quite important in planning for Mars missions that involve aerobraking.

The temperature profiles in Mars-GRAM are built from parameterizations that estimate temperatures at significant levels (0, 5, 15, 30, 50 and 75-km altitudes). To allow user-controlled input incorporating the effects of temperature changes since the Viking era, a set of climate factor values may be input to Mars-GRAM version 3.4. These factors, specified by values of the climate adjustment factors (CF array), are multiplicative factors that alter temperatures derived from the original parameterizations in Mars-GRAM. For example, if all temperature values (from surface to 75 km) are to be increased by 10%, use values of 1.1 for all CF array elements. For a decrease of all temperatures by 10% use CF values of 0.9. Separate CF values may be selected at each significant level altitude (see section 6).

After the effects of the climate factor array are included in the temperature estimates, effects on the pressure and density variations with altitude are then computed by applying the hydrostatic balance equation and perfect gas law to the temperature profile values.

Together with adjustment parameters for the thermospheric variables (deltaTEX, deltaTF, and deltaZF), the climate adjustment factors now allow maximum flexibility in adjusting Mars-GRAM results to reproduce the temperature, pressure, and density expected under any specific simulation case. Appendix A lists all changes in the program code required to incorporate the new climate change factors.

6. Revised Program Execution Procedures

Operation of the interactive form of Mars-GRAM is unchanged. Note however, that input values for the climate adjustment factors (CF array) and thermospheric adjustment parameters are not accepted by the interactive form (only default values of CF = 1 and $\Delta\text{TEX} = \Delta\text{TF} = \Delta\text{ZF} = 0$ are allowed in interactive mode).

In the batch form of Mars-GRAM, input is provided via the NAMELIST file INPUT. The complete set of values for the reference INPUT file is as follows:

```
$INPUT
  LSTFL  = 'LIST',      ! List file name (CON for console listing)
  OUTFL  = 'OUTPUT',   ! Output file name
  MONTH  = 7,          ! month of year
  MDAY   = 20,         ! day of month
  MYEAR  = 76,         ! year (4-digit; 1970-2069 can be 2-digit)
  NPOS   = 11,         ! max # positions to evaluate (0 = read from TRAJDATA)
  IHR    = 12,         ! GMT hour of day
  IMIN   = 30,         ! minute of hour
  SEC    = 0.0,        ! second of minute (for initial position)
  ALS0   = 0.0,        ! starting Ls value (degrees) for dust storm (0 = none)
  INTENS = 0.0,        ! dust storm intensity (0.0 - 3.0)
  RADMAX = 0.0,        ! max. radius (km) of dust storm (0 or >10000 = global)
  DUSTLAT = 0.0,       ! latitude (deg) for center of dust storm
  DUSTLON = 0.0,       ! West longitude (deg) of center of dust storm
  F107   = 68.0,       ! 10.7 cm solar flux (10**-22 W/cm**2 at 1 AU)
  STDL   = 0.0,        ! std. dev. for thermosphere variation (-3.0 to +3.0)
  MODPERT = 3,         ! perturbation model; 1=random, 2=wave, 3=both
  NR1    = 1001,       ! starting random number (0 < NR1 < 30000)
  NVARX  = 1,          ! x-code for plotable output (1=hgt above ref. ellipse)
  NVARY  = 0,          ! y-code for 2-D plotable output (0 for 1-D plots)
  LOGSCALE = 0,        ! 0=linear scale, 1=log scale, 2=COSPAR % deviations
  FLAT   = 22.0,       ! initial latitude (N positive), degrees
  FLON   = 48.0,       ! initial longitude (West positive), degrees
  FHGT   = -0.5,       ! initial height (km), above ref. ellipse
  DELHGT = 10.0,       ! height increment (km) between steps
  DELLAT = 0.0,        ! latitude increment (deg) between steps
  DELLON = 0.0,        ! West longitude increment (deg) between steps
  DELTIME = 0.0,       ! time increment (sec) between steps
  CF0    = 1.0,        ! climate adjustment factor at surface
  CF5    = 1.0,        ! climate adjustment factor at 5 km
  CF15   = 1.0,        ! climate adjustment factor at 15 km
  CF30   = 1.0,        ! climate adjustment factor at 30 km
  CF50   = 1.0,        ! climate adjustment factor at 50 km
  CF75   = 1.0,        ! climate adjustment factor at 75 km
  deltaZF = 0.0,       ! adjustment for base of thermosphere (km)
  deltaTF = 0.0,       ! adjustment for temperature at height ZF (K)
  deltaTEX = 0.0,      ! adjustment for exospheric temperature (K)
$END
```

The newly required inputs are CF0 through CF75 (climate adjustment factors at significant levels 0, 5, 15, 30, 50 and 75 km) and the thermospheric adjustment parameters (ΔZF for base height of the thermosphere, ΔTF for temperature of the base of the thermosphere, and ΔTEX for the exospheric temperature).

A new feature of Mars-GRAM is that values of the input parameters are needed as input into the NAMELIST INPUT files only if they differ from the default values listed above. Thus, the output for the above reference case is generated by using an empty INPUT file, namely,

\$INPUT
\$END

The reference LIST output file for the reference input case above is given in Appendix B and contains values for latitude and longitude of the sub-solar point, the heliocentric distance (Mars orbital radius), and if the altitude is above 75 km, the local exospheric temperature and the local height and temperature of the base of the thermosphere.

7. References

1. Bougher, S.W., et al. (1988): "Mars Thermospheric General Circulation Model: Calculations for the Arrival of Phobos at Mars", *Geophys. Res. Lett.*, 15(13), 1511-1514.
2. Bougher, S.W. (1995): Comparative Thermospheres: Venus and Mars", *Adv. Space Res.*, 15(4), 21-45.
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7. Justus, C.G. (1990): "A Mars Global Reference Atmospheric Model (Mars-GRAM) for Mission Planning and Analysis", AIAA 90-004, 28th Aerospace Sciences meeting, Reno, NV, January.
8. Justus, C.G. (1991): "Mars Global Reference Atmospheric Model for Mission Planning and Analysis", *J. Spacecraft and Rockets*, 28(2), 216-221.
9. Justus, C.G., Bonnie F. James and Dale L. Johnson (1996): "Mars Global Reference Atmospheric Model (Mars-GRAM version 3.34): Programmer's Guide", NASA TMX XXXX, April, 1996.
10. Pitts, David E. et al. (1990?): "The Mars Atmosphere: Observations and Model Profiles for Mars Missions, NASA JSC-24455.
11. Stewart, A.I.F. (1987): Revised Time Dependent Model of the Martian Atmosphere for use in Orbit Lifetime and Sustenance Studies", Final report JPL PO# NQ-802429, March 26, 52 pp.

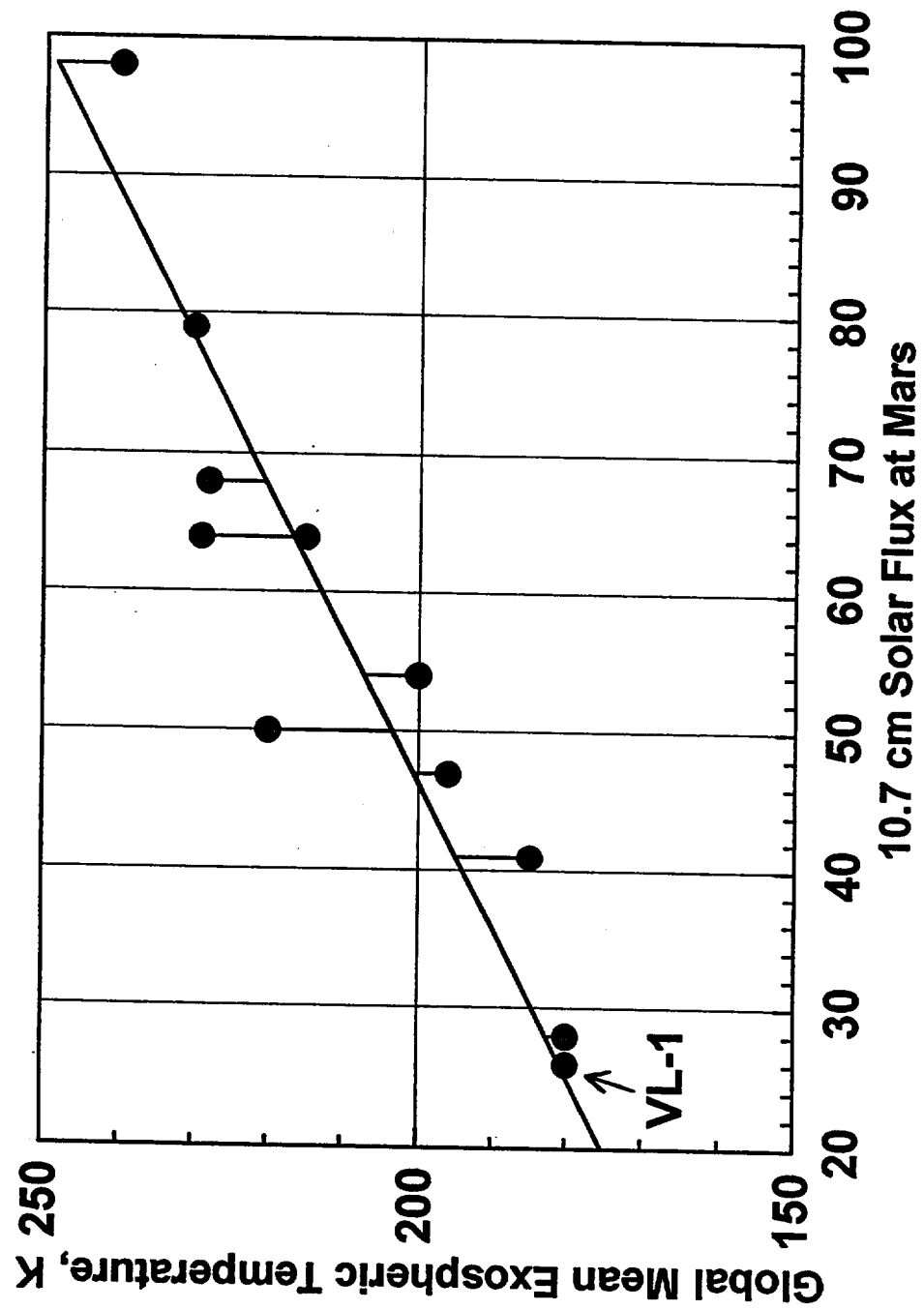


Figure 2.1. Global mean exospheric temperature (K), versus 10.7 cm solar flux. Data are from Table 2.1. The regression line is equation (2.1).

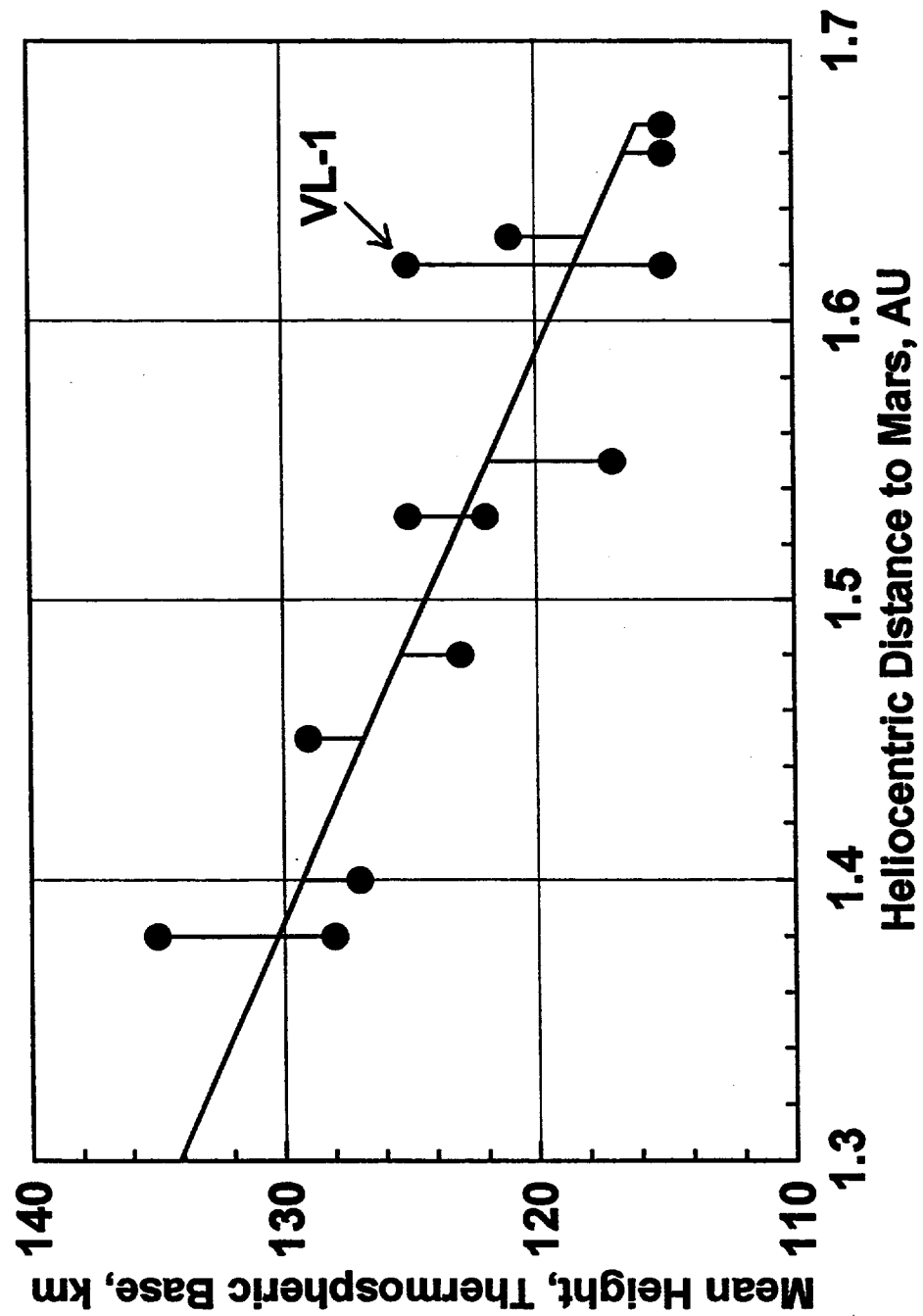


Figure 2.2. Global mean height (km) of the base of the thermosphere, versus heliocentric distance. Data are from Table 2.1. The regression line is equation (2.2).

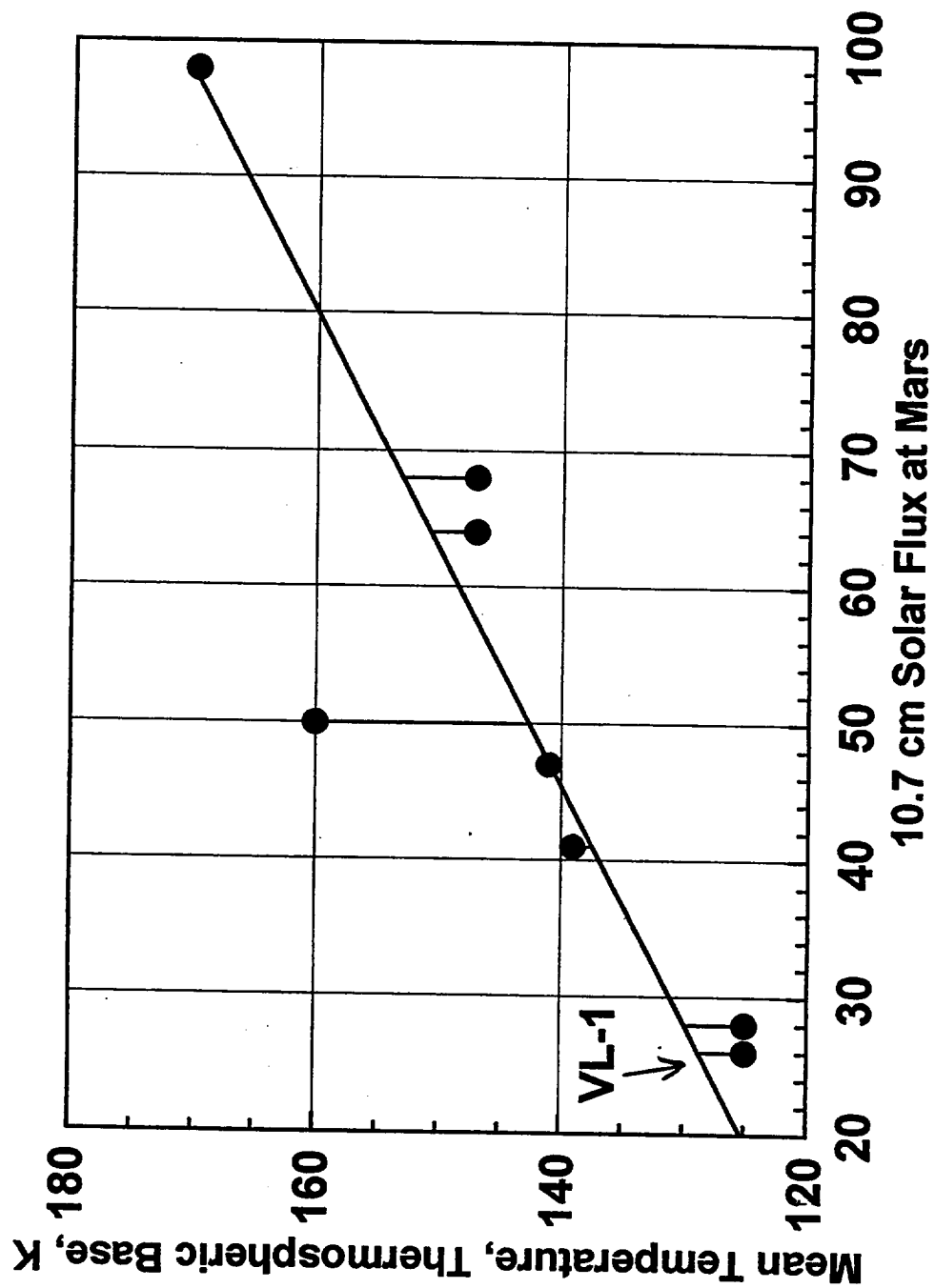


Figure 2.3. Global mean temperature (K) at the base of the thermosphere, versus 10.7 cm solar flux. Data are from Table 2.1. The regression line is equation (2.3).

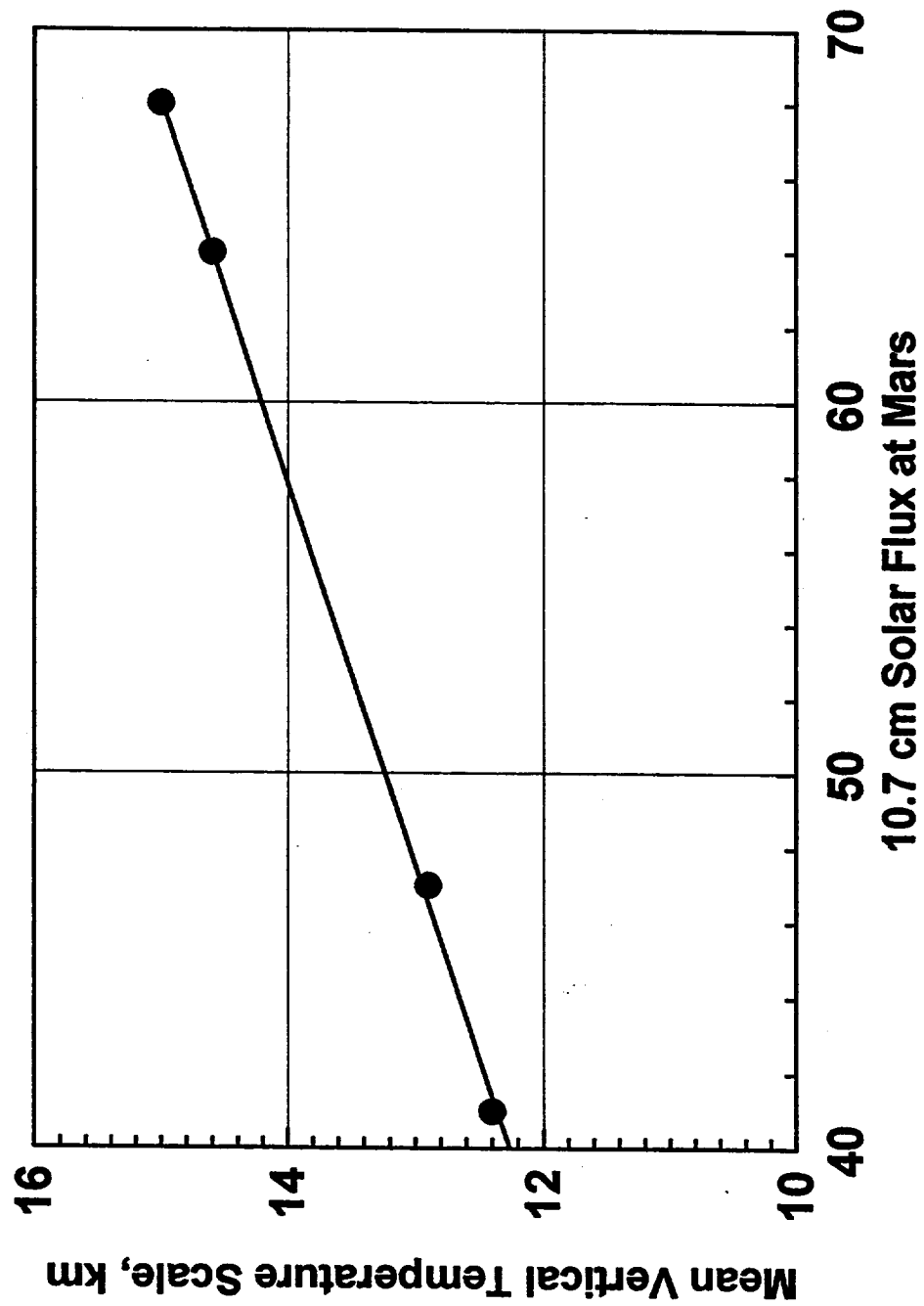


Figure 2.4. Global mean vertical thermospheric temperature scale (km), versus 10.7 cm solar flux. Data are from Table 2.1. The regression line is equation (2.4).

MTGCM Case MGS98L, 220 km Height

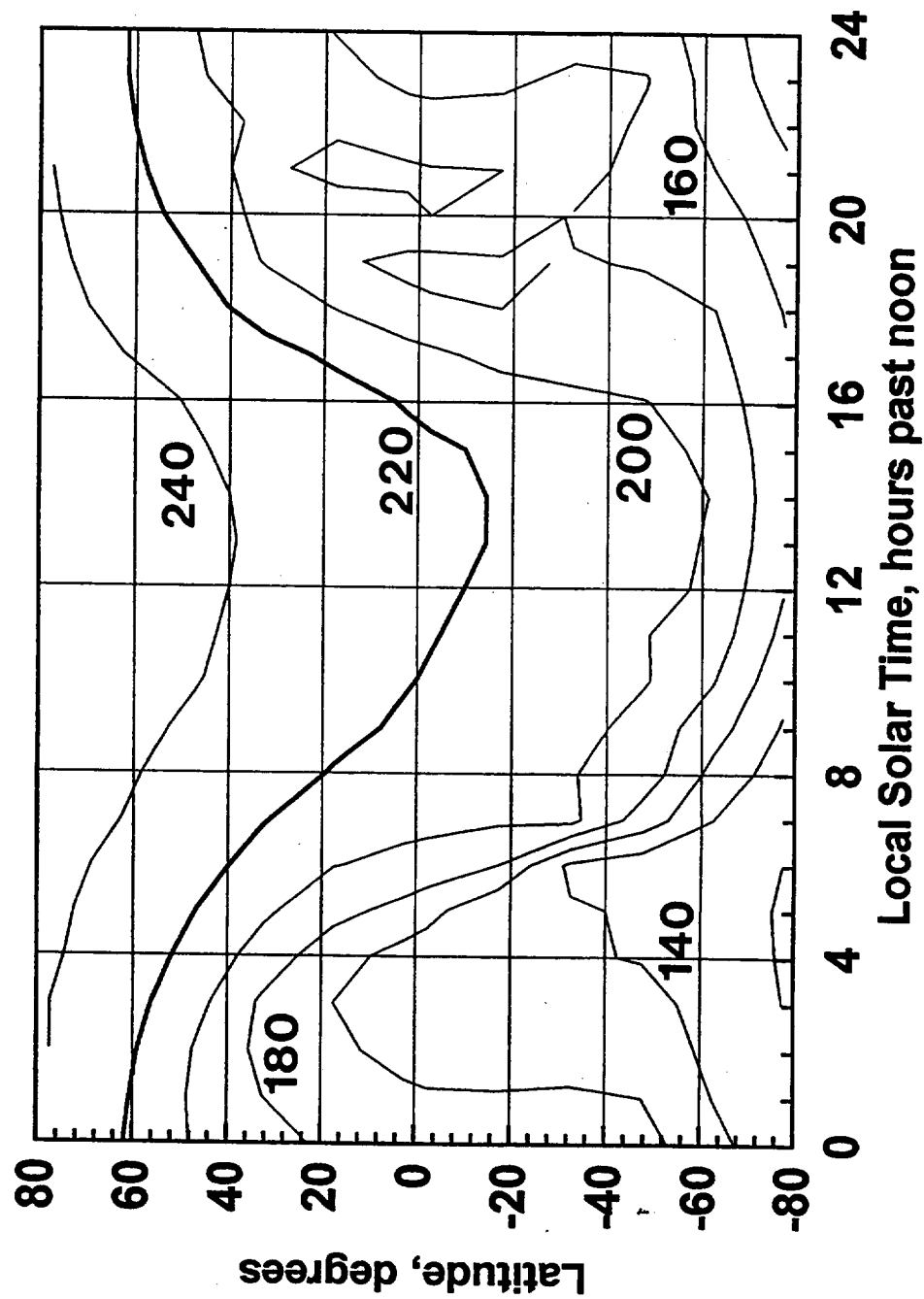


Figure 3.1. MTGCM model exospheric temperature (K) versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

Mars-GRAM Case MGS98L, 230 km Height

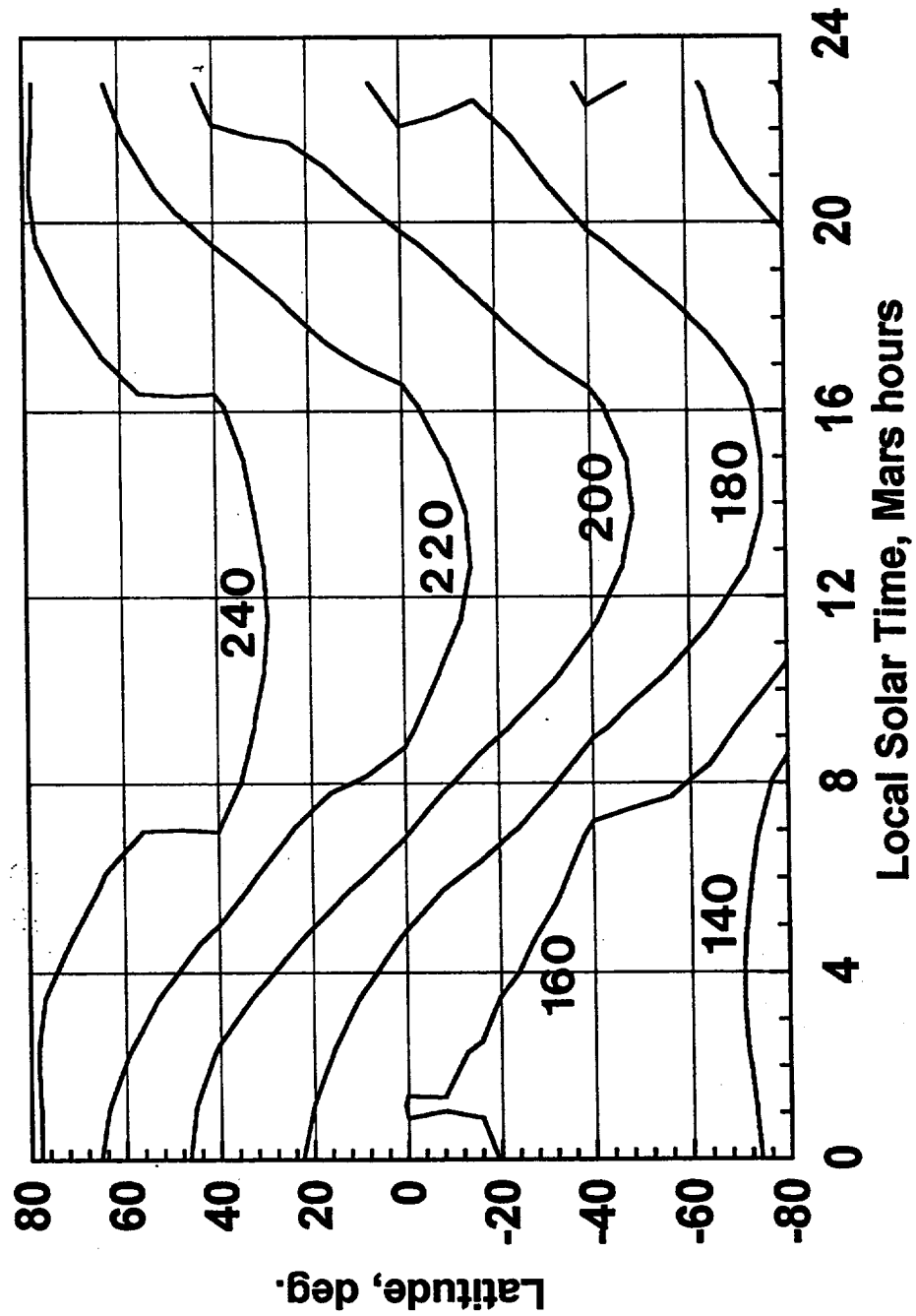


Figure 3.2. Mars-GRAM model exospheric temperature (K) versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

MTGCM Case MGS97L, 220 km Height

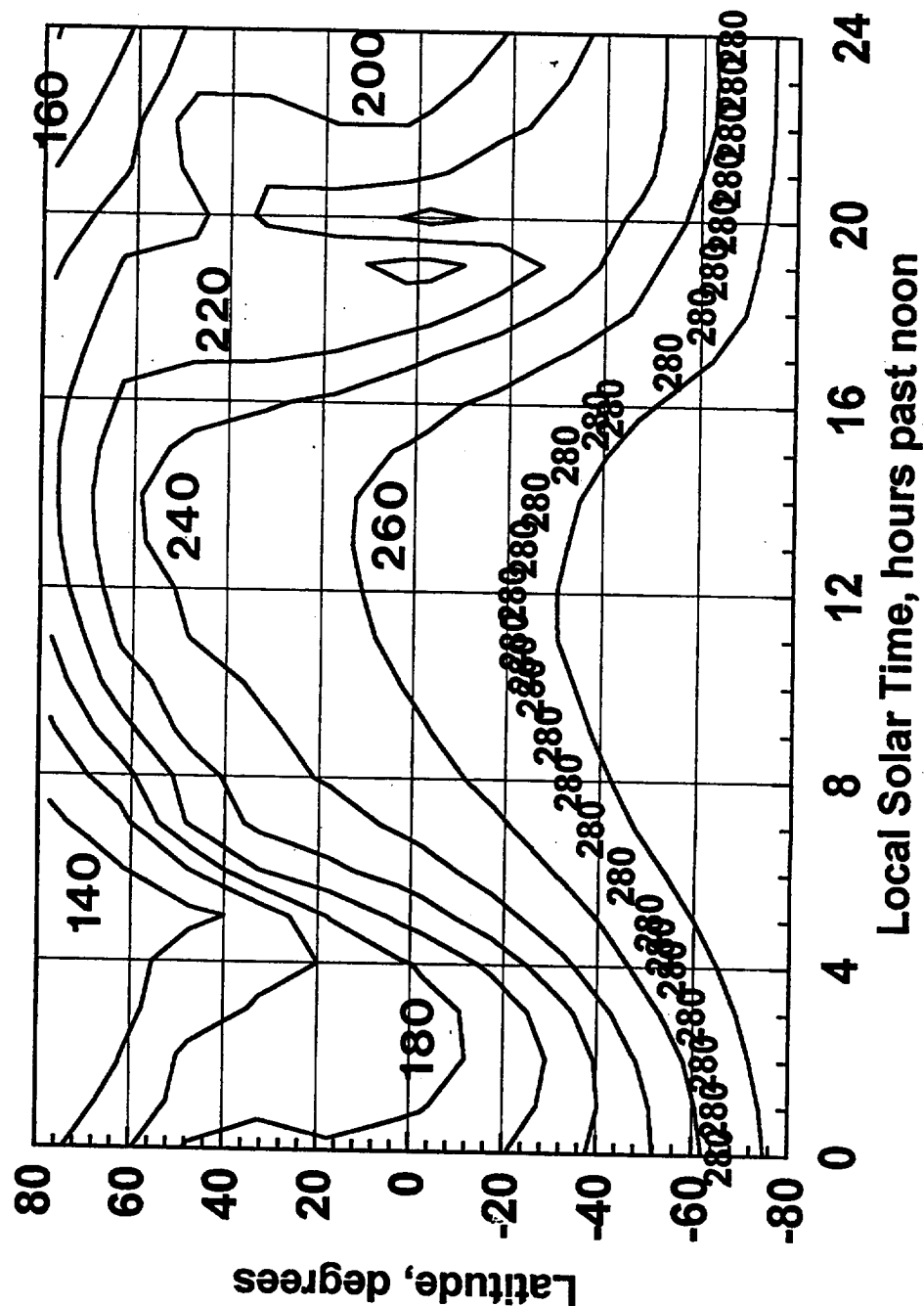


Figure 3.3. MTGCM model exospheric temperature (K) versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters.

MarsGRAM MGS97L Case, 230 km Height

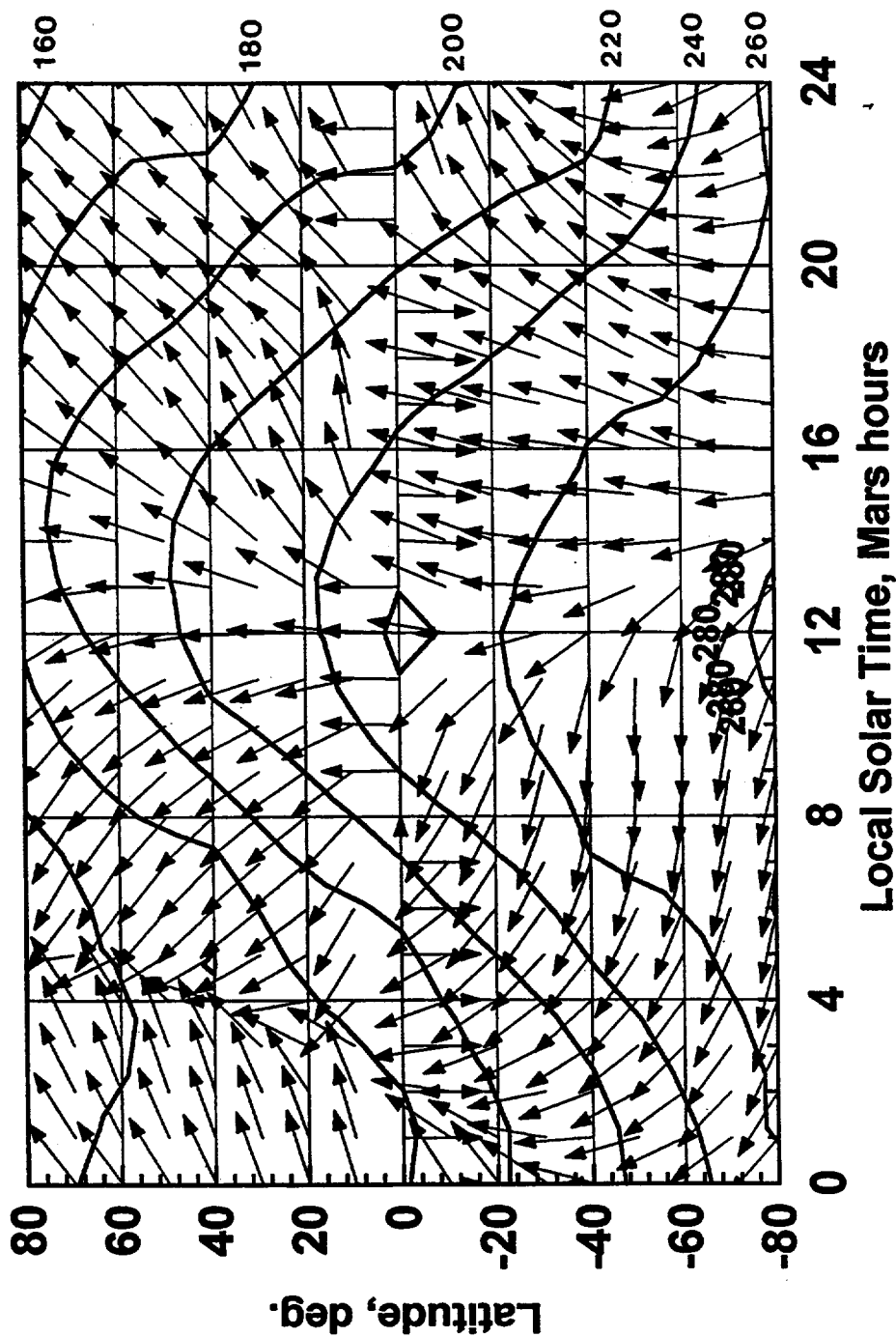


Figure 3.4. Mars-GRAM model exospheric temperature (K) versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters. Wind speed vectors range from 0 to 129 m/s.

MTGCM MGS98L Case, 180 km Height

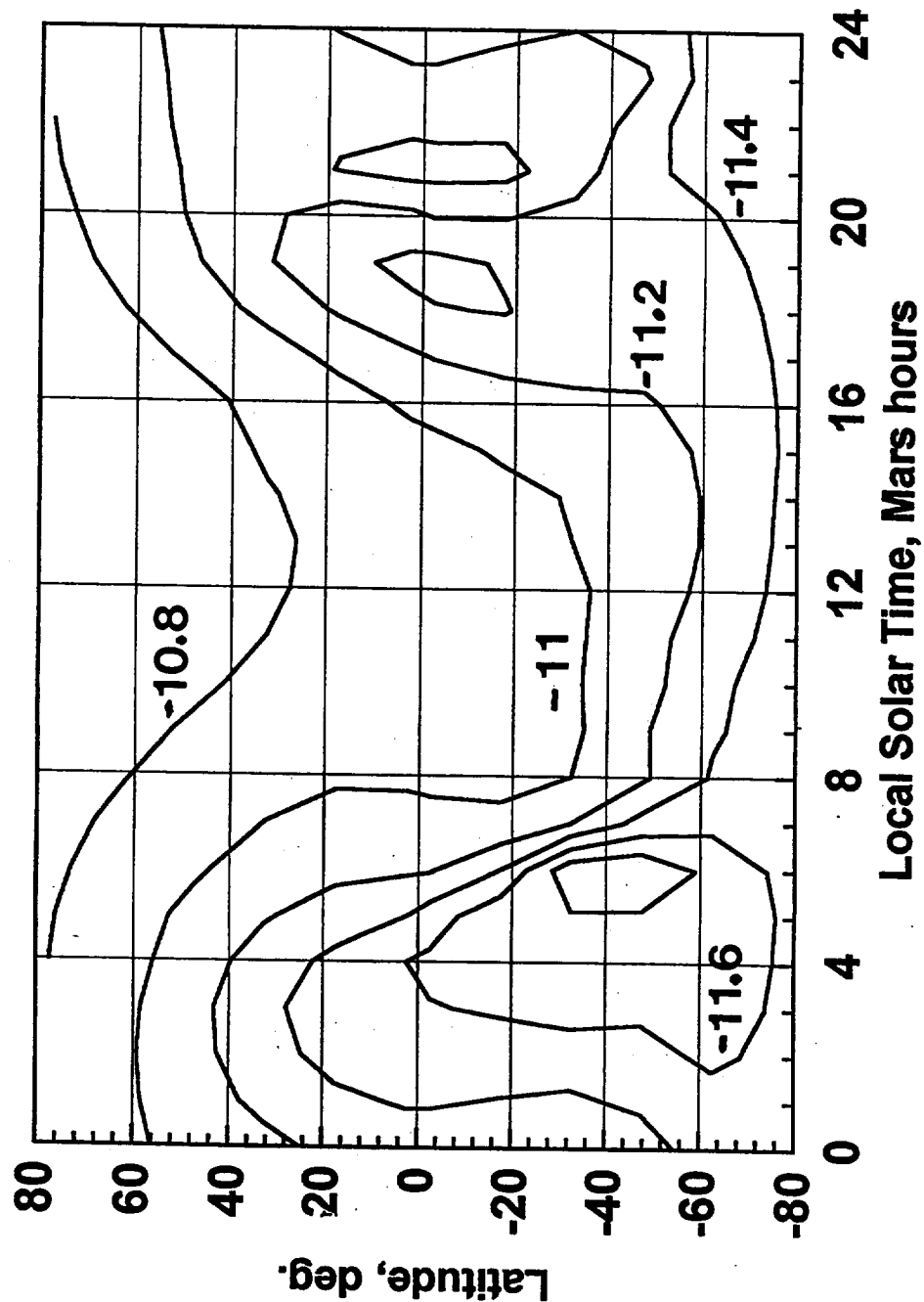


Figure 3.5. MTGCM model density (log-base-10, kg/m³) at 180 km height, versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

Mars-GRAM MGS98L Case, 180 km Height

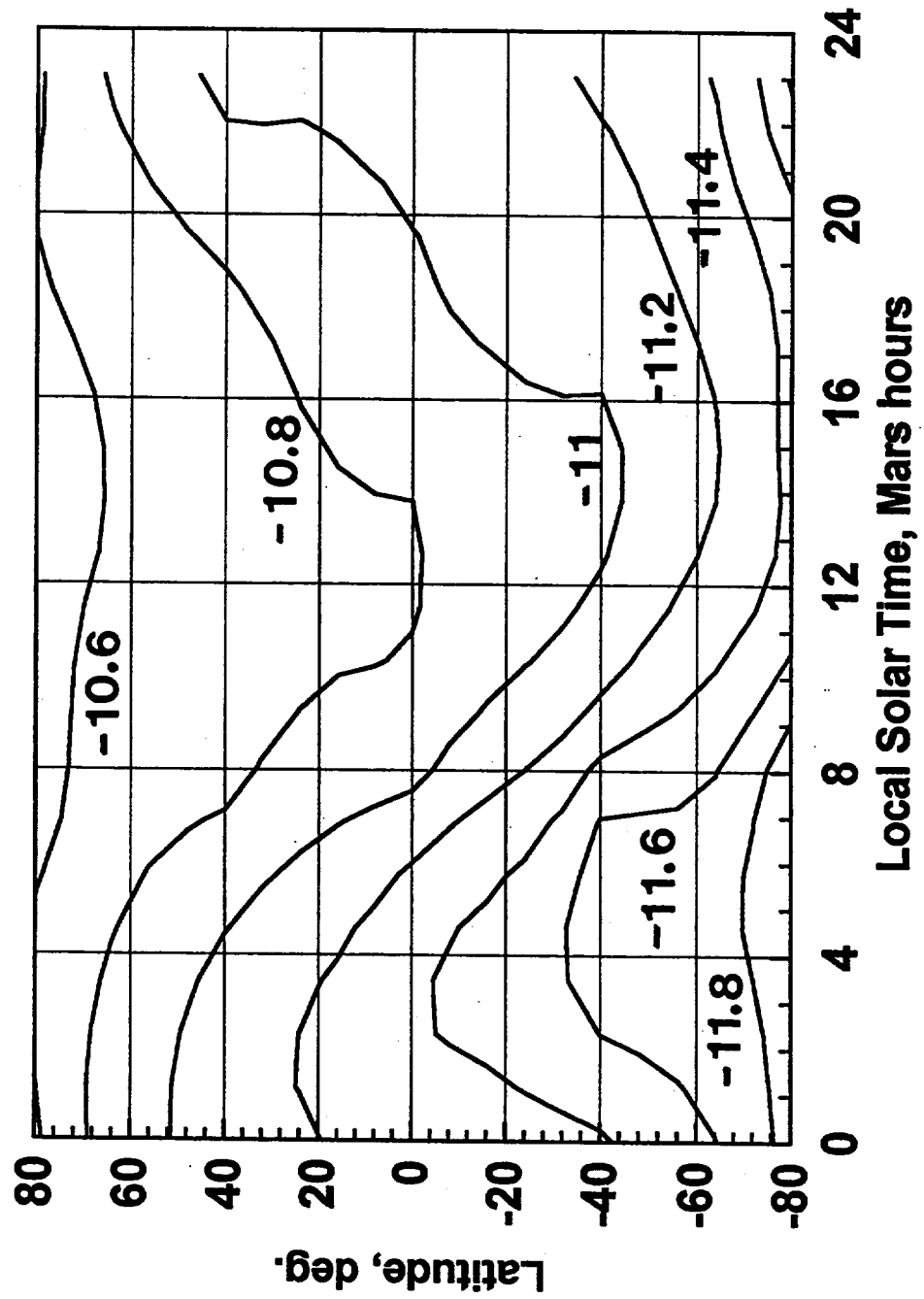


Figure 3.6. Mars-GRAM model density (log-base-10, kg/m³) at 180 km height, versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

MTGCM MGS97L Case, 180 km Height

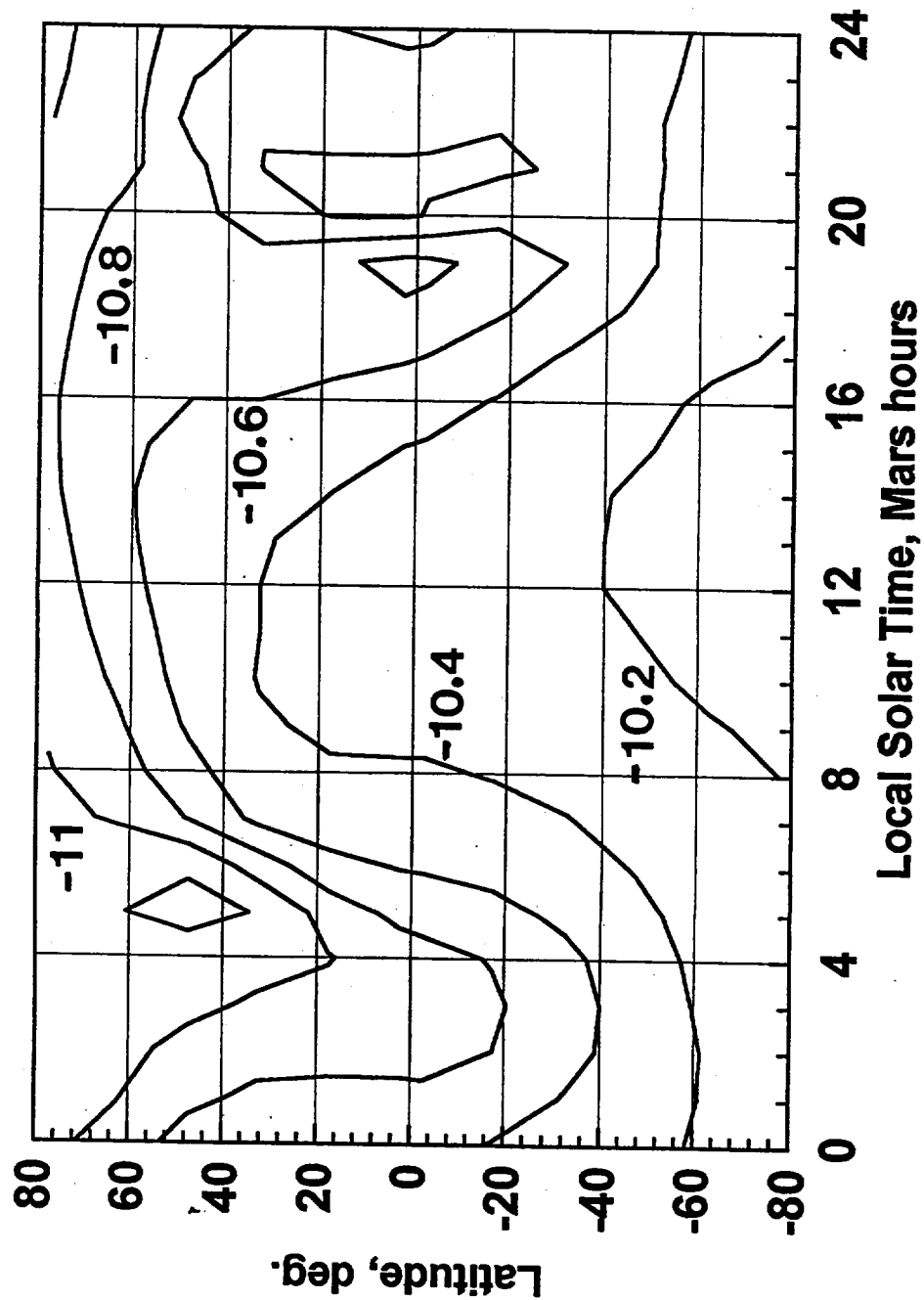


Figure 3.7. MTGCM model density (log-base-10, kg/m³) at 180 km height, versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters.

MarsGRAM MGS97L Case, 180 km Height

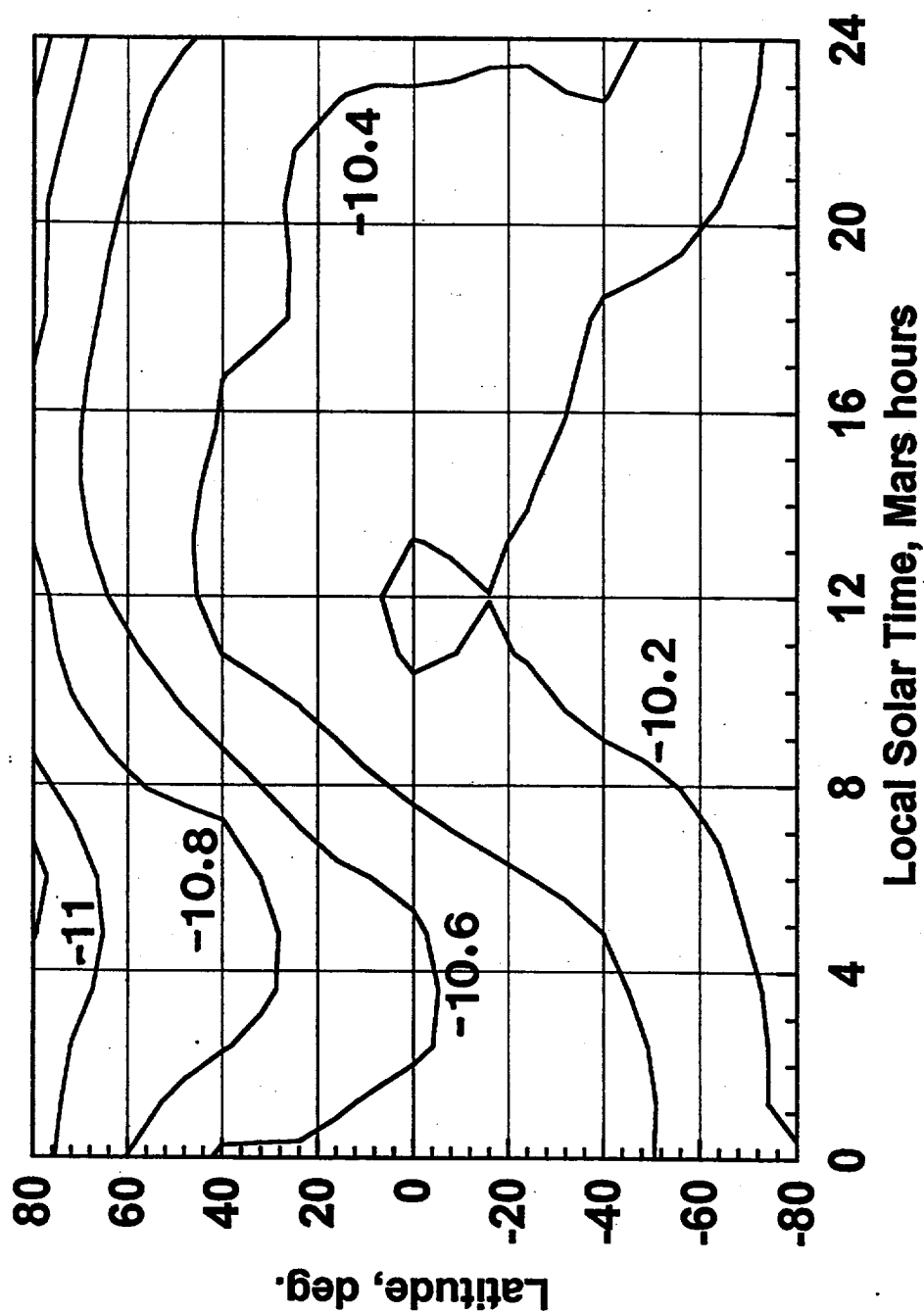


Figure 3.8. Mars-GRAM model density (log-base-10, kg/m³) at 180 km height, versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters.

MTGCM Case MGS98L, TF(K)

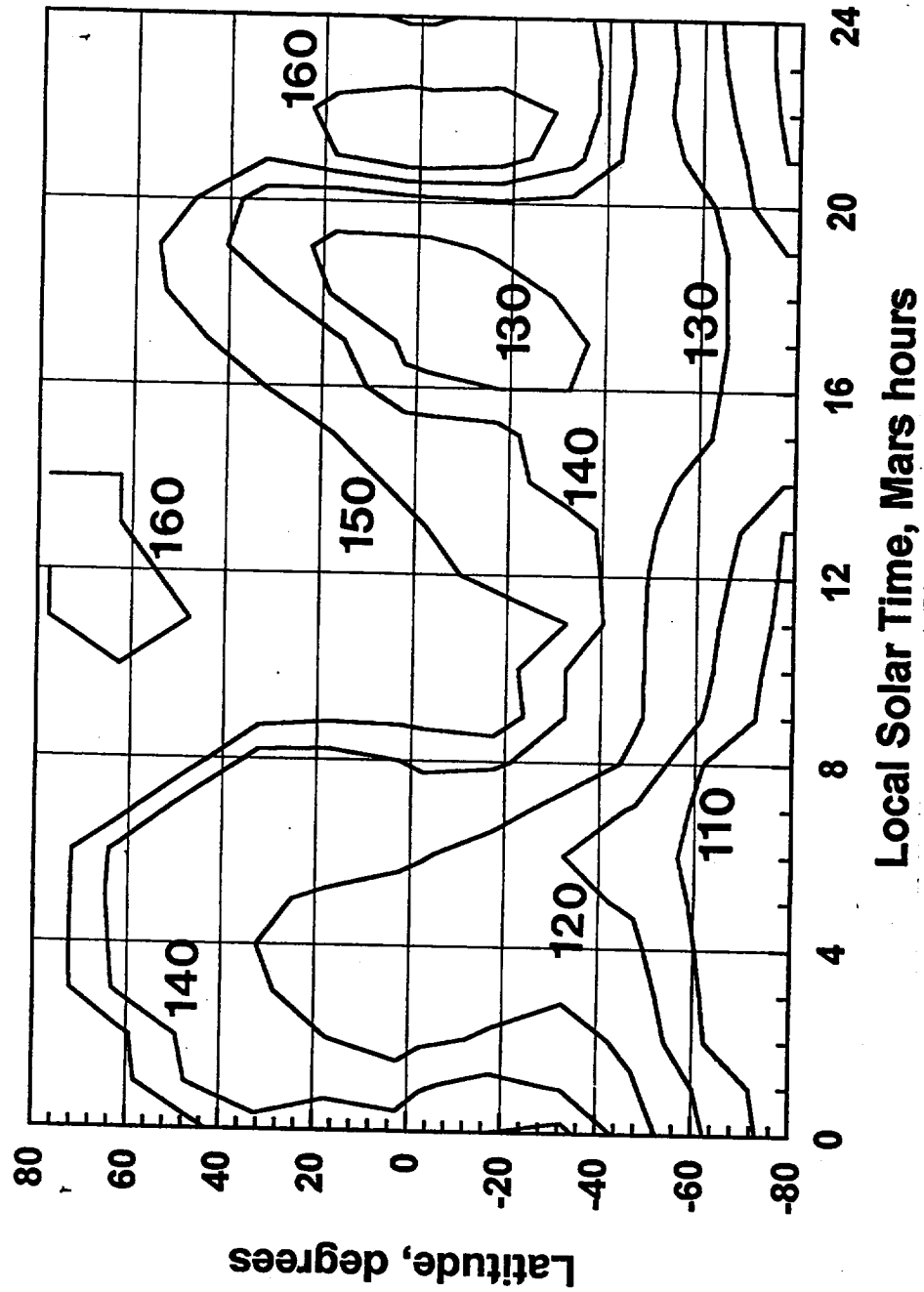


Figure 3.9. MTGCM model temperature (K) at base of the thermosphere, versus latitude and time of day for model case MGS98L. See Table 2.1 for values of model case parameters.

MarsGRAM MGS97L Case, 130 km Height

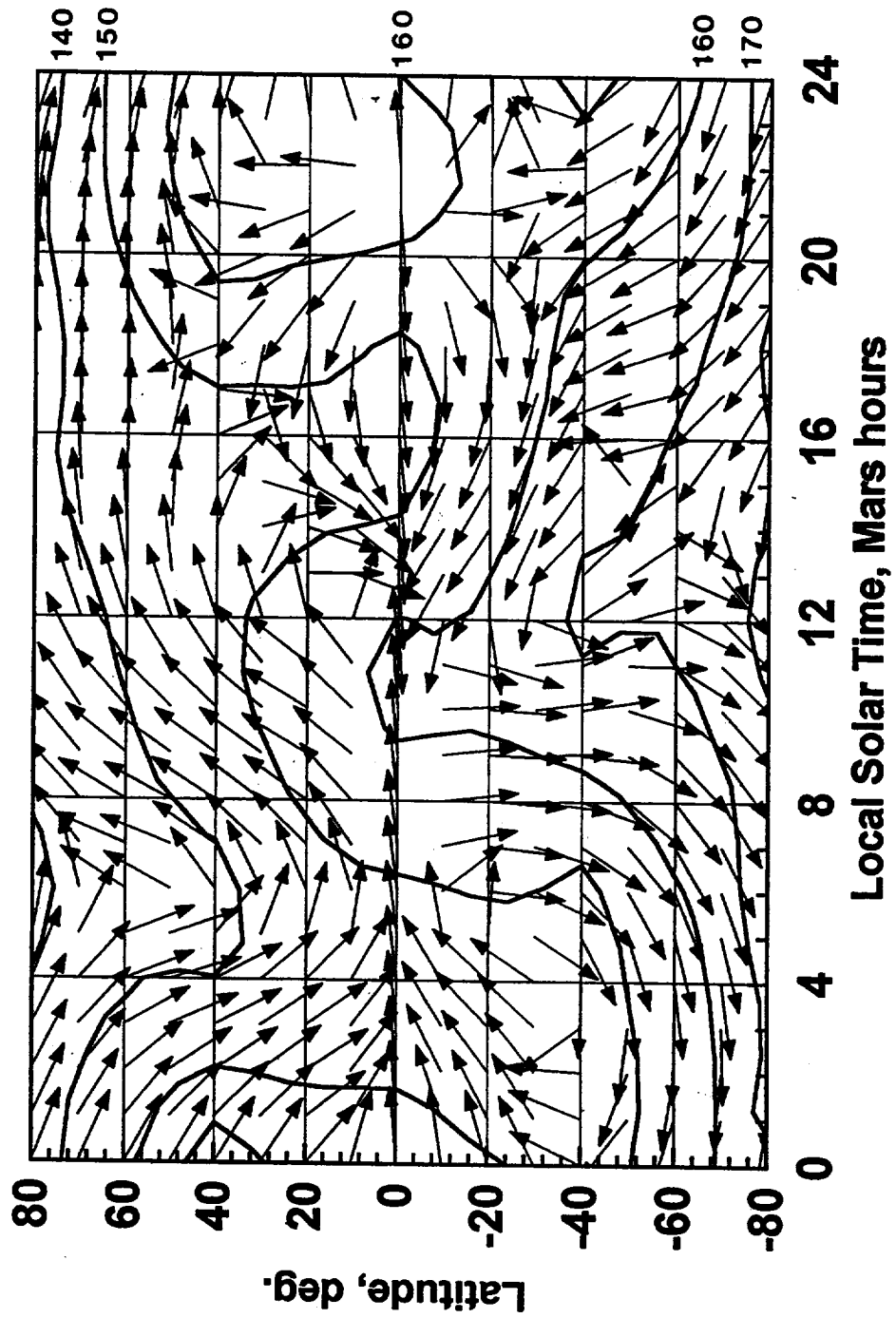


Figure 3.10. MarsGRAM model temperature (K) at 130 km height, versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters. Wind speed vectors range from 0 to 188 m/s.

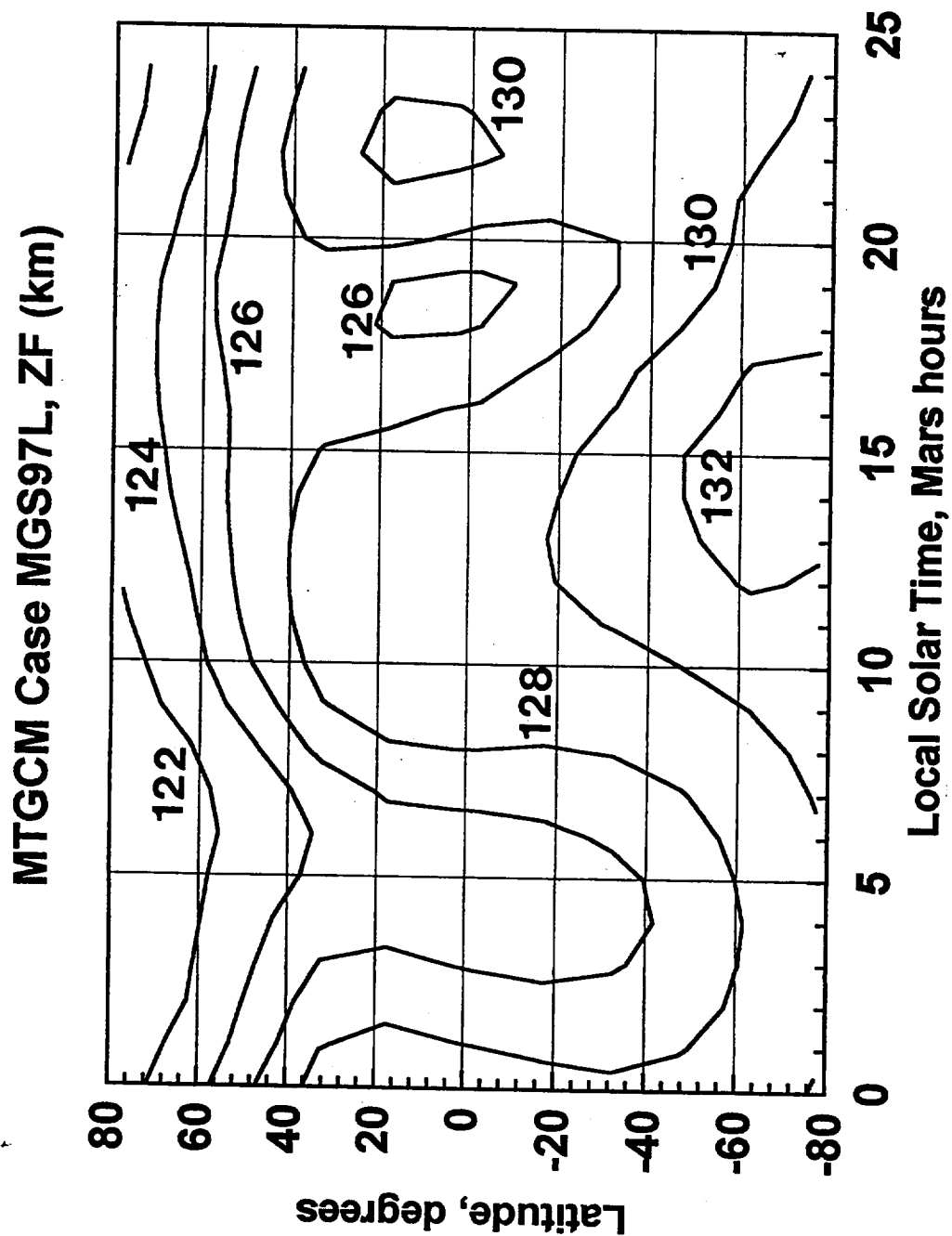


Figure 3.11. MTGCM model height (km) of the base of the thermosphere, versus latitude and time of day for model case MGS97L. See Table 2.1 for values of model case parameters.

MTGCM Case MGS97L, Latitude 62.5 N

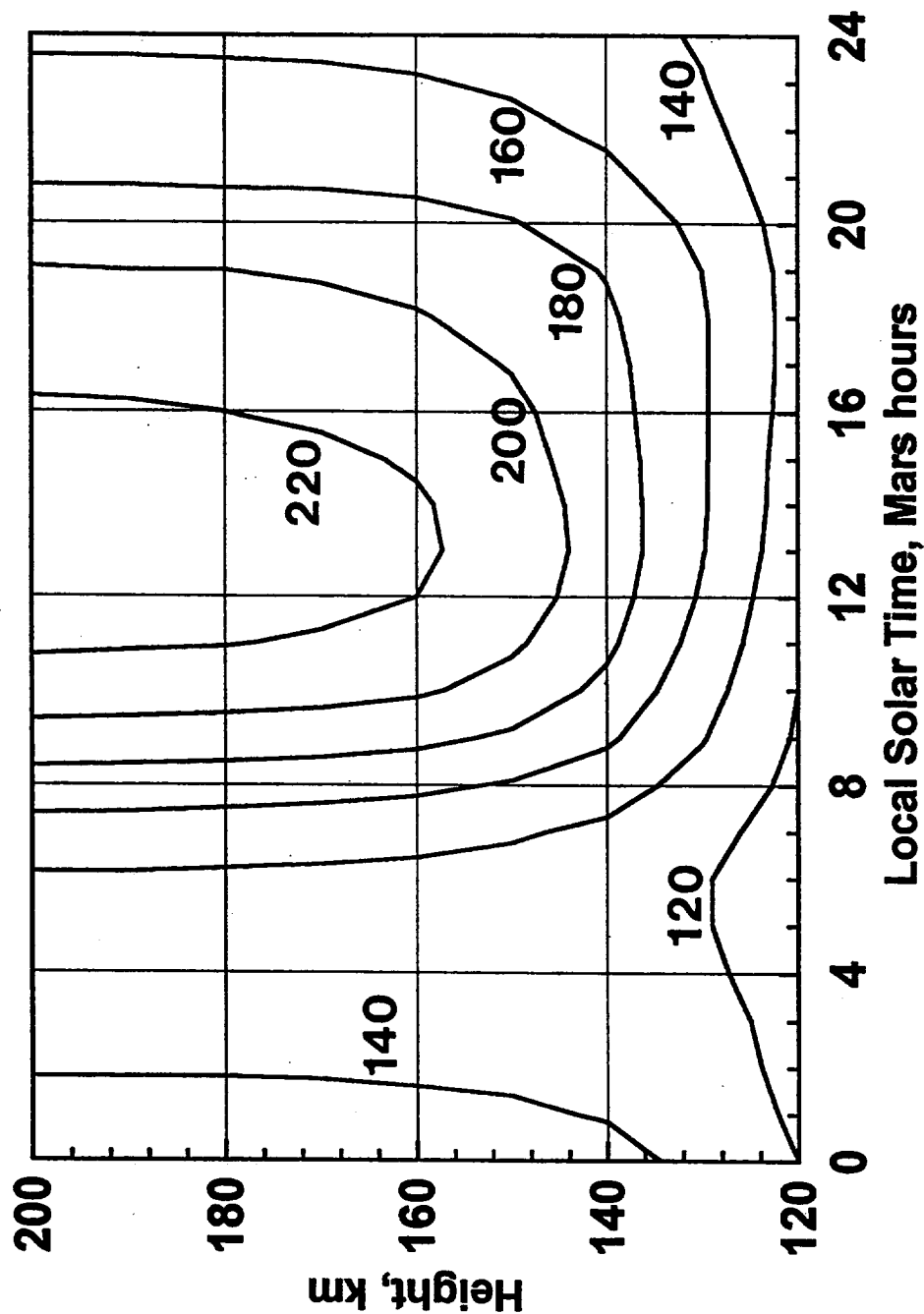


Figure 3.12. MTGCM model temperature (K) , versus height and time of day at latitude 62.5 degrees North, for model case MGS97L. See Table 2.1 for values of model case parameters.

Mars-GRAM MGS97L, Latitude 62.5 deg

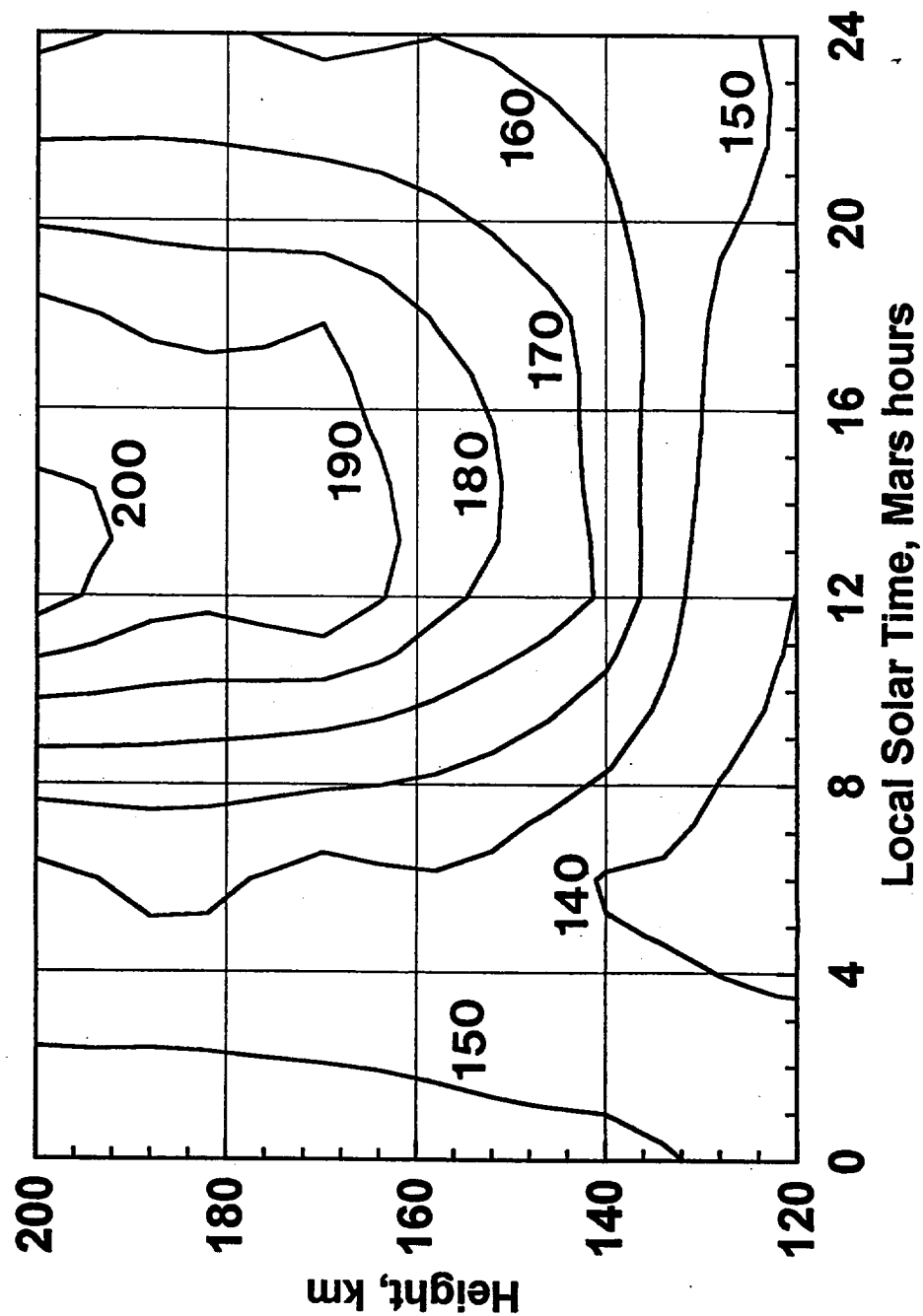


Figure 3.13. Mars-GRAM model temperature (K) , versus height and time of day at latitude 62.5 degrees North, for model case MGS97L. See Table 2.1 for values of model case parameters.

Appendix A - Updates in the Mars-GRAM Program Code

1. Comparing MARSGRAM.FOR for Mars-GRAM 3.34 and Mars-GRAM 3.4

The official version number is changed.

```

***** Mars-GRAM 3.34\MARSGRAM.FOR
C... Program Mars-GRAM Interactive version 3.34 - November 1, 1995      MARS 1
C                                                                           MARS 2
***** Mars-GRAM 3.4\MARSGRAM.FOR
C... Program Mars-GRAM Interactive version 3.4 - April 1, 1996          MARS 1
C                                                                           MARS 2
*****

```

Output of the official version number to the LIST file is changed.

```

***** Mars-GRAM 3.34\MARSGRAM.FOR
C                                                                           MARS 10
1 Format(' Mars-GRAM Interactive version 3.34 - November 1, 1995')      MARS 11
C                                                                           MARS 12
***** Mars-GRAM 3.4\MARSGRAM.FOR
C                                                                           MARS 10
1 Format(' Mars-GRAM Interactive version 3.4 - April 1, 1996')          MARS 11
C                                                                           MARS 12
*****

```

Climate factors (CF) and thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX) are added to the common DATACOM.

```

***** Mars-GRAM 3.34\MARSGRAM.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,           MARS 22
& intens,iu0,iup,maxfiles                                             MARS 23
COMMON /FILENAME/lstfl,outfl                                          MARS 24
***** Mars-GRAM 3.4\MARSGRAM.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,           MARS 22
& intens,iu0,iup,maxfiles,CF(0:5),deltaZF,deltaTF,deltaTEX           MARS 23
COMMON /FILENAME/lstfl,outfl                                          MARS 24
*****

```

The climate factors (CF) are initialized to their default values of 1.0. The thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX) are initialized to their default values of 0.0. User selected values of these parameters can be used in the batch form of Mars-GRAM. In the interactive form of Mars-GRAM, these parameters cannot be changed from their default values.

```

***** Mars-GRAM 3.34\MARSGRAM.FOR
Write(iu0,10)                                                         MARS 44
10 format(' Enter name for LIST file (CON for console listing): ')    MARS 45
***** Mars-GRAM 3.4\MARSGRAM.FOR
Write(iu0,10)                                                         MARS 44
C... Set CF climate factors to 1.0 (.ne. 1 available in Batch version) MARS 44a
Do 5 i = 0,5                                                         MARS 44b
CF(i) = 1.0                                                         MARS 44c
5 Continue                                                           MARS 44d
C... Set deltaZF, deltaTF & deltaTEX to 0.0 (available in Batch only) MARS 44e
deltaZF = 0.0                                                         MARS 44f
deltaTF = 0.0                                                         MARS 44g
deltaTEX = 0.0                                                         MARS 44h
10 format(' Enter name for LIST file (CON for console listing): ')    MARS 45
*****

```

2. Comparing MARSGRMB.FOR for Mars-GRAM 3.34 and Mars-GRAM 3.4

The official version number is changed.

```

***** Mars-GRAM 3.34\MARSGRMB.FOR
C... Program Mars-GRAM Batch version 3.34 - November 1, 1995      MARB 1
C                                                                    MARB 2
***** Mars-GRAM 3.4\MARSGRMB.FOR
C... Program Mars-GRAM Batch version 3.4 - April 1, 1996          MARB 1
C                                                                    MARB 2
*****

```

The default value of solar flux at 1AU (F107) is changed to 68, from 185. The 1AU value of F107 on the day of the Viking 1 landing (July 20, 1976) was 68.

```

***** Mars-GRAM 3.34\MARSGRMB.FOR
C DUSTLON = 0.0,      ! West longitude (deg) of center of dust storm  MARB 35
C F107     = 185.0,    ! 10.7 cm solar flux (10**-22 W/cm**2 at 1 AU) MARB 36
C STD L    = 0.0,      ! std. dev. for thermosphere variation (-3.0  MARB 37
***** Mars-GRAM 3.4\MARSGRMB.FOR
C DUSTLON = 0.0,      ! West longitude (deg) of center of dust storm  MARB 35
C F107     = 68.0,     ! 10.7 cm solar flux (10**-22 W/cm**2 at 1 AU) MARB 36
C STD L    = 0.0,      ! std. dev. for thermosphere variation (-3.0  MARB 37
*****

```

The comment about the COSPAR model comparison (LOGSCALE = 2) is added.

```

***** Mars-GRAM 3.34\MARSGRMB.FOR
C                                !                               plots)  MARB 44
C LOGSCALE = 0,                 ! 1 for log-base-10 scale plots, 0 for linear  MARB 45
C                                !                               scale    MARB 46
C FLAT      = 22.0,             ! initial latitude (N positive), degrees  MARB 47
***** Mars-GRAM 3.4\MARSGRMB.FOR
C                                !                               plots)  MARB 44
C LOGSCALE = 0,                 ! 0=regular linear scale, 1=log-base-10 scale,  MARB 45
C                                ! 2=percentage deviations from COSPAR model  MARB 46
C FLAT      = 22.0,             ! initial latitude (N positive), degrees  MARB 47
*****

```

Descriptions are added to the NAMELIST input for the new climate adjustment factors (CF) and thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX).

```

***** Mars-GRAM 3.34\MARSGRMB.FOR
C DELTIME  = 0.0,      ! time increment (sec) between steps      MARB 53
C $END                                           MARB 54
***** Mars-GRAM 3.4\MARSGRMB.FOR
C DELTIME  = 0.0,      ! time increment (sec) between steps      MARB 53
C CF0       = 1.0,      ! climate adjustment factor at surface  MARB 53a
C CF5       = 1.0,      ! climate adjustment factor at 5 km      MARB 53b
C CF15      = 1.0,      ! climate adjustment factor at 15 km     MARB 53c
C CF30      = 1.0,      ! climate adjustment factor at 30 km     MARB 53d
C CF50      = 1.0,      ! climate adjustment factor at 50 km     MARB 53e
C CF75      = 1.0,      ! climate adjustment factor at 75 km     MARB 53f
C deltaZF   = 0.0,      ! adjustment for base of thermosphere (km)  MARB 53g
C deltaTF   = 0.0,      ! adjustment for temperature at height ZF (K)  MARB 53h
C deltaTEX  = 0.0,      ! adjustment for exospheric temperature (K)  MARB 53i
C                                                    MARB 53j
C $END                                           MARB 54
*****

```

3. Comparing MARSSUBS.FOR for Mars-GRAM 3.34 and Mars-GRAM 3.4

The official version number is changed.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
C      Subroutines and Functions for Interactive and Batch versions of   ALBL 1
C      Mars-GRAM version 3.34 - November 1, 1995                         ALBL 2
C.....ALBL 3
***** Mars-GRAM 3.4\MARSSUBS.FOR
C      Subroutines and Functions for Interactive and Batch versions of   ALBL 1
C      Mars-GRAM version 3.4 - April 1, 1996                           ALBL 2
C.....ALBL 3
*****

```

The climate adjustment factors (CF) and the thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX) are added to the argument list for subroutine ATMOS2. The local exospheric temperature (Texos) and local temperature of the base of the thermosphere (Tbase) are added as output arguments, to pass these values for output to the LIST file.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      & dustM,dustA,H,TEMP,DENST,UPFCTR,LWFCTR,PRES,RSC,Z0,TMAX,TMIN,      ATM2  2
      & TAVG,Bruntf,densurf,tfactor,ZF,als0,intens,iu0)                  ATM2  3
      REAL LWFCTR,MARSAU,INTENS                                          ATM2  4
***** Mars-GRAM 3.4\MARSSUBS.FOR
      & dustM,dustA,H,TEMP,DENST,UPFCTR,LWFCTR,PRES,RSC,Z0,TMAX,TMIN,      ATM2  2
      & TAVG,Bruntf,densurf,tfactor,ZF,als0,intens,iu0,CF,deltaZF,      ATM2  3
      & deltaTF,deltaTEX,Texas,Tbase)                                    ATM2  3a
      REAL LWFCTR,MARSAU,INTENS                                          ATM2  4
*****

```

Comments about the input/output argument list for ATMOS2 are updated, to reflect the new argument variables.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
COMMON /THERM/F107, stdl
Dimension ES(0:11)
C
C
C   CHGT    SPACECRAFT HEIGHT ABOVE REFERENCE SURFACE (KM) (INPUT)
C   CLAT    APACECRAFT LATITUDE (DEGREES) (INPUT)
C   CLON    WEST LONGITUDE OF SPACECRAFT (DEGREES) (INPUT)
C   MARSAU  MARS ORBITAL RADIUS (AU) (INPUT)
C   SUNLAT  AREOCENTRIC LATITUDE OF SUN (DEGREES) (INPUT)
C   SUNLON  MARS WEST LONGITUDE OF SUN (DEGREES) (INPUT)
C   ALS     AREOCENTRIC LONGITUDE OF SUN ORBIT (INPUT)
C   DATE    JULIAN DATE (INPUT)
C   dustM   dust storm magnitude for average T and p effect
C           (1 = full magnitude, 0 = no dust storm) (INPUT)
C   dustA   dust storm magnitude for daily amplitude T and p effect
C           (1 = full magnitude, 0 = no dust storm) (INPUT)
C   H       SCALE HEIGHT AT SPACECRAFT POSITION (KM) (OUTPUT)
C   TEMP    TEMPERATURE AT SPACECRAFT POSITION (K) (OUTPUT)
C   DENST   MASS DENSITY AT SPACECRAFT POSITION (KG/M**3) (OUTPUT)
C   UPFCTR  UPPER DEVIATION FACTOR ON MASS DENSITY (OUTPUT)
C   LWFCTR  LOWER DEVIATION FACTOR ON MASS DENSITY (OUTPUT)
C   PRES    PRESSURE AT SPACECRAFT POSITION (N/M**2) (OUTPUT)
C   RSC     AREOCENTRIC RADIUS TO SPACECRAFT (KM) (OUTPUT)
C   Z0      LOCAL TERRAIN HEIGHT RELATIVE TO REFERENCE ELLIPSOID
C           (KM) (INPUT)
C   TMAX    Daily maximum surface temperature (K) (OUTPUT)
C   TMIN    Daily minimum surface temperature (K) (OUTPUT)
C   TAVG    Daily average surface temperature (K) (OUTPUT)
C   Bruntf  Brunt-Vaisala frequency = Sqrt((g/T)*(dT/dZ + g/Cp))
C           (OUTPUT)

```

C	densurf	Density at surface (kg/m**3) (OUTPUT)	ATM2 34
C	tfactor	Density perturbation factor at base of thermosphere (OUTPUT)	ATM2 35
C	ZF	Height of base of thermosphere (OUTPUT)	ATM2 36
C	als0	Initial Ls for dust storm	ATM2 37
C	INTENS	Dust storm intensity (0.0-3.0)	ATM2 38
C	iu0	unit number for messages	ATM2 39
C			ATM2 40
C			ATM2 41
***** Mars-GRAM 3.4\MARSSUBS.FOR			
	COMMON	/THERM/F107,std1	ATM2 5
	Dimension	ES(0:11),CF(0:5)	ATM2 6
C			ATM2 7
C	CHGT	SPACECRAFT HEIGHT ABOVE REFERENCE SURFACE (KM) (INPUT)	ATM2 8
C	CLAT	SPACECRAFT LATITUDE (DEGREES) (INPUT)	ATM2 9
C	CLON	WEST LONGITUDE OF SPACECRAFT (DEGREES) (INPUT)	ATM2 10
C	MARSAU	MARS ORBITAL RADIUS (AU) (INPUT)	ATM2 11
C	SUNLAT	AREOCENTRIC LATITUDE OF SUN (DEGREES) (INPUT)	ATM2 12
C	SUNLON	MARS WEST LONGITUDE OF SUN (DEGREES) (INPUT)	ATM2 13
C	ALS	AREOCENTRIC LONGITUDE OF SUN ORBIT (INPUT)	ATM2 14
C	DATE	JULIAN DATE (INPUT)	ATM2 15
C	dustM	dust storm magnitude for average T and p effect (1 = full magnitude, 0 = no dust storm) (INPUT)	ATM2 16
C	dustA	dust storm magnitude for daily amplitude T and p effect (1 = full magnitude, 0 = no dust storm) (INPUT)	ATM2 17
C	H	SCALE HEIGHT AT SPACECRAFT POSITION (KM) (OUTPUT)	ATM2 18
C	TEMP	TEMPERATURE AT SPACECRAFT POSITION (K) (OUTPUT)	ATM2 19
C	DENST	MASS DENSITY AT SPACECRAFT POSITION (KG/M**3) (OUTPUT)	ATM2 20
C	UPFCTR	UPPER DEVIATION FACTOR ON MASS DENSITY (OUTPUT)	ATM2 21
C	LWFCTR	LOWER DEVIATION FACTOR ON MASS DENSITY (OUTPUT)	ATM2 22
C	PRES	PRESSURE AT SPACECRAFT POSITION (N/M**2) (OUTPUT)	ATM2 23
C	RSC	AREOCENTRIC RADIUS TO SPACECRAFT (KM) (OUTPUT)	ATM2 24
C	Z0	LOCAL TERRAIN HEIGHT RELATIVE TO REFERENCE ELLIPSOID (KM) (INPUT)	ATM2 25
C	TMAX	Daily maximum surface temperature (K) (OUTPUT)	ATM2 26
C	TMIN	Daily minimum surface temperature (K) (OUTPUT)	ATM2 27
C	TAVG	Daily average surface temperature (K) (OUTPUT)	ATM2 28
C	Bruntf	Brunt-Vaisala frequency = Sqrt((g/T)*(dT/dZ + g/Cp)) (OUTPUT)	ATM2 29
C	densurf	Density at surface (kg/m**3) (OUTPUT)	ATM2 30
C	tfactor	Density perturbation factor at base of thermosphere (OUTPUT)	ATM2 31
C	ZF	Local height of base of thermosphere (OUTPUT)	ATM2 32
C	als0	Initial Ls for dust storm	ATM2 33
C	INTENS	Dust storm intensity (0.0-3.0)	ATM2 34
C	iu0	unit number for messages	ATM2 35
C	CF	climate adjustment factor array for temperature levels	ATM2 36
C	deltaZF	adjustment in height (km) of base of thermosphere	ATM2 37
C	deltaTF	adjustment in temperature (K) at height ZF	ATM2 38
C	deltaTEX	adjustment in exospheric temperature (K)	ATM2 39
C	Texos	local exospheric temperature (K) (OUTPUT)	ATM2 40
C	Tbase	local temperature for base of exosphere (K) (OUTPUT)	ATM2 40a
C			ATM2 40b
C			ATM2 40c
C			ATM2 40d
C			ATM2 40e
C			ATM2 40f
C			ATM2 41

The climate adjustment factors (CF) are added to the argument list of the subroutine TEMPS.

***** Mars-GRAM 3.34\MARSSUBS.FOR			
C...	Evaluate temperatures at significant levels		ATM2 68
	Call Temps(T0bar,Tsurf,gam,CLAT,dlon,dustM,dustA,ALS,T)		ATM2 69
C...	Evaluate surface pressure, N/m**2		ATM2 70
***** Mars-GRAM 3.4\MARSSUBS.FOR			
C...	Evaluate temperatures at significant levels		ATM2 68
	Call Temps(T0bar,Tsurf,gam,CLAT,dlon,dustM,dustA,ALS,T,CF)		ATM2 69
C...	Evaluate surface pressure, N/m**2		ATM2 70

The local height of the base of the thermosphere (ZF) is computed, by calling the new subroutine Thermpar, and applying the Stewart (ES), pressure (DR), and dust corrections. The calling order for the Stewart2 subroutine is modified, to improve the program logic and run-time efficiency. This is the section that calls Stewart2 for use in the interpolation between 75 km altitude and the base of the thermosphere. The temperatures at the base of the thermosphere (Tbase) and in the exosphere (Texos) are passed for output to the LIST file.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
C...   Height of base of thermosphere                      ATM2136
      ZF = 124.4 * (SMA / MARSAU)*EXP(ES(8)) + DR + DUST    ATM2137
C...   Shgt = height for call to thermosphere model        ATM2138
C...   Shgt = ZF if current height < ZF                    ATM2139
      Shgt = CHGT                                           ATM2140
      If (CHGT .lt. ZF) Shgt = ZF                           ATM2141
C...   Evaluate atmospheric parameters at base of thermosphere ATM2142
      Call Stewart2(MARSAU,ALS,CLAT,TIME,PRES,TEMP,DENST,    ATM2143
&     Shgt,Rstar,H,AMF,0.0,als0,INTENS,iu0)                 ATM2144
C...   Evaluate density perturbation factor at base of thermosphere ATM2145
      Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESHI,TEMPHI,      ATM2146
&     DENSHI,Shgt,Rstar,HHI,AMHI,1.0,als0,INTENS,iu0)       ATM2147
      tfactor = DENSHI/DENST - 1.0                          ATM2148
C...   Use stratosphere model if current height < ZF       ATM2149
      If (CHGT .lt. ZF)then                                  ATM2150
        PF = PRES                                           ATM2151
***** Mars-GRAM 3.4\MARSSUBS.FOR
C...   Height of base of thermosphere                      ATM2136
      Call Thermpar(MARSAU,70.,CLAT,TIME,SUNLAT,TINF0,TF0,ZF0,SCALE) ATM2136a
      ZF = ZF0*EXP(ES(8)) + DR + DUST + deltaZF             ATM2137
C...   Use stratosphere model if current height < ZF       ATM2149
      If (CHGT .lt. ZF)then                                  ATM2149a
        Shgt = ZF                                           ATM2149b
C...   Evaluate thermospheric parameters at base of thermosphere ATM2149c
      Call Stewart2(MARSAU,ALS,CLAT,TIME,PRES,TEMP,DENST,Shgt, ATM2149d
&     Rstar,H,AMF,0.0,als0,INTENS,iu0,sunlat,deltaZF,deltaTF, ATM2149e
&     deltaTEX,TINF,TF)                                     ATM2149f
      Tbase = TF                                           ATM2149g
      Texos = TINF                                         ATM2149h
C...   Evaluate density perturbation factor at base of thermosphere ATM2149i
      Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESHI,TEMPHI,      ATM2149j
&     DENSHI,Shgt,Rstar,HHI,AMHI,1.0,als0,INTENS,iu0,sunlat, ATM2149k
&     deltaZF,deltaTF,deltaTEX,TINF,TF)                   ATM2149l
      tfactor = DENSHI/DENST - 1.0                          ATM2149m
      PF = PRES                                           ATM2151
*****

```

The calling order for the Stewart2 subroutine is modified, to improve the program logic and run-time efficiency. This is the section that calls Stewart2 within the thermosphere. The temperatures at the base of the thermosphere (Tbase) and in the exosphere (Texos) are passed for output to the LIST file.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      Else
        Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESHI,          ATM2163
&     TEMPHI,DENSHI,Shgt,Rstar,HHI,AMHI,1.0,als0,INTENS,iu0) ATM2164
        Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESLO,          ATM2165
&     TEMPLO,DENSLO,Shgt,Rstar,HLO,AMLO,-1.0,als0,INTENS,iu0) ATM2166
        UPFCTR = DENSHI/DENST                                ATM2167
***** Mars-GRAM 3.4\MARSSUBS.FOR
      Else
        Shgt = CHGT                                           ATM2163
C...   Evaluate thermospheric parameters at current height ATM2163a
      Call Stewart2(MARSAU,ALS,CLAT,TIME,PRES,TEMP,DENST,    ATM2163b
&

```

```

&      Shgt,Rstar,H,AMF,0.0,als0,INTENS,iu0,sunlat,deltaZF,deltaTF, ATM2163d
&      deltaTEX,TINF,TF) ATM2163e
Texos = TINF ATM2163f
Tbase = TF ATM2163g
tfactor = DENSHI/DENST - 1.0 ATM2163h
Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESHI,TEMPHI, ATM2164
&      DENSHI,Shgt,Rstar,HHI,AMHI,1.0,als0,INTENS,iu0,sunlat, ATM2165
&      deltaZF,deltaTF,deltaTEX,TINF,TF) ATM2165a
Call Stewart2(MARSAU,ALS,CLAT,TIME,PRESLO,TEMPLO, ATM2166
&      DENSL0,Shgt,Rstar,HLO,AMLO,-1.0,als0,INTENS,iu0,sunlat, ATM2167
&      deltaZF,deltaTF,deltaTEX,TINF,TF) ATM2167a
UPFCTR = DENSHI/DENST ATM2168
*****

```

Adjustment parameters CF, deltaZF, deltaTF, and deltaTEX are added to the common DATACOM.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0, BLKD 8
& intens,iu0,iup,maxfiles BLKD 9
C... Unit numbers for messages (normally to screen) and to list output BLKD 10
***** Mars-GRAM 3.4\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0, BLKD 8
& intens,iu0,iup,maxfiles,CF(0:5),deltaZF,deltaTF,deltaTEX BLKD 9
C... Unit numbers for messages (normally to screen) and to list output BLKD 10
*****

```

Data statements are added, to establish default parameters. Note, the parameter maxfiles may need to be 16, for PC-based, 16-bit compilers. This will limit the number of output files that will be produced; maxfiles may be set to a larger value on UNIX systems and 32-bit PC compilers.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
Data maxfiles/16/ BLKD 18
C... Zurek wave perturbation parameter data values BLKD 19
***** Mars-GRAM 3.4\MARSSUBS.FOR
Data maxfiles/16/ BLKD 18
C... Default = no dust storm BLKD 18a
Data Als0,Intens,Radmax,Dustlat,Dustlon/5*0.0/ BLKD 18b
C... Default model parameters BLKD 18c
Data Modpert,NVARX,NVARY,LOGSCALE,NPOS/3,1,0,0,21/ BLKD 18d
C... Zurek wave perturbation parameter data values BLKD 19
*****

```

Adjustment parameters CF, deltaZF, deltaTF, and deltaTEX are added to the common DATACOM.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0, DSTF 11
& intens,iu0,iup,maxfiles DSTF 12
Real intens DSTF 13
***** Mars-GRAM 3.4\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0, DSTF 11
& intens,iu0,iup,maxfiles,CF(0:5),deltaZF,deltaTF,deltaTEX DSTF 12
Real intens DSTF 13
*****

```

Adjustment parameters CF, deltaZF, deltaTF, and deltaTEX are added to the common DATACOM.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0, DSTP 9
& intens,iu0,iup,maxfiles DSTP 10

```

```

COMMON /FILENAME/1stfl,outfl
**** Mars-GRAM 3.4\MARSSUBS.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,
& intens,iu0,iup,maxfiles,CF(0:5),deltaZF,deltaTF,deltaTEX
COMMON /FILENAME/1stfl,outfl
****

```

DSTP 11
DSTP 9
DSTP 10
DSTP 11

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texas, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```

**** Mars-GRAM 3.34\MARSSUBS.FOR
& dustM,dustA,HSCALE,TEMP,DENS,FACTHI,FACTLO,PRES,RSC,thgt,
& TMAX,TMIN,TAVG,Bruntf,densurf,tfactor,ZF,als0,INTENS,iu0)
C... CHGT = height above reference ellipsoid
**** Mars-GRAM 3.4\MARSSUBS.FOR
& dustM,dustA,HSCALE,TEMP,DENS,FACTHI,FACTLO,PRES,RSC,thgt,
& TMAX,TMIN,TAVG,Bruntf,densurf,tfactor,ZF,als0,INTENS,iu0,CF,
& deltaZF,deltaTF,deltaTEX,Texas,Tbase)
Zbase = ZF
C... CHGT = height above reference ellipsoid
****

```

DSTP 41
DSTP 42
DSTP 43
DSTP 41
DSTP 42
DSTP 42a
DSTP 42b
DSTP 43

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texas, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```

**** Mars-GRAM 3.34\MARSSUBS.FOR
& dustM,dustA,HLONP,TLONP,DLONP,FHI,FLO,PLONP,RLONP,thgt,
& TMAP,TMIP,TAVP,bvf,den0,tfac,zf,als0,INTENS,iu0)
CLONM = CLON - 2.5
**** Mars-GRAM 3.4\MARSSUBS.FOR
& dustM,dustA,HLONP,TLONP,DLONP,FHI,FLO,PLONP,RLONP,thgt,
& TMAP,TMIP,TAVP,bvf,den0,tfac,zf,als0,INTENS,iu0,CF,deltaZF,
& deltaTF,deltaTEX,TINF,TF)
CLONM = CLON - 2.5
****

```

DSTP 87
DSTP 88
DSTP 89
DSTP 87
DSTP 88
DSTP 88a
DSTP 89

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texas, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```

**** Mars-GRAM 3.34\MARSSUBS.FOR
& dustM,dustA,HLONM,TLONM,DLONM,FHI,FLO,PLONM,RLONM,thgt,
& TMAM,TMIM,TAVM,bvf,den0,tfac,zf,als0,INTENS,iu0)
C... First two heights for area average height
**** Mars-GRAM 3.4\MARSSUBS.FOR
& dustM,dustA,HLONM,TLONM,DLONM,FHI,FLO,PLONM,RLONM,thgt,
& TMAM,TMIM,TAVM,bvf,den0,tfac,zf,als0,INTENS,iu0,CF,deltaZF,
& deltaTF,deltaTEX,TINF,TF)
C... First two heights for area average height
****

```

DSTP 92
DSTP 93
DSTP 94
DSTP 92
DSTP 93
DSTP 93a
DSTP 94

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texas, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```

**** Mars-GRAM 3.34\MARSSUBS.FOR
& dustM,dustA,HLATP,TLATP,DLATP,FHI,FLO,PLATP,RLATP,thgt,
& TMAP,TMIP,TAVP,bvf,den0,tfac,zf,als0,INTENS,iu0)
CLATM = CLAT - 2.5
**** Mars-GRAM 3.4\MARSSUBS.FOR
& dustM,dustA,HLATP,TLATP,DLATP,FHI,FLO,PLATP,RLATP,thgt,
& TMAP,TMIP,TAVP,bvf,den0,tfac,zf,als0,INTENS,iu0,CF,deltaZF,
& deltaTF,deltaTEX,TINF,TF)
CLATM = CLAT - 2.5
****

```

DSTP105
DSTP106
DSTP107
DSTP105
DSTP106
DSTP106a
DSTP107

The new input and output parameters (CF, deltaZF, deltaTF, deltaTEX, Texas, and Tbase) are added to the argument list in the call statement for subroutine ATMOS2.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      & dustM,dustA,HLATM,TLATM,DLATM,FHI,FLO,PLATM,RLATM,thgt,          DSTP114
      & TMAM,TMIM,TAVM,bvf,den0,tfac,zt,als0,INTENS,iu0)                DSTP115
C... Area average height                                              DSTP116
***** Mars-GRAM 3.4\MARSSUBS.FOR
      & dustM,dustA,HLATM,TLATM,DLATM,FHI,FLO,PLATM,RLATM,thgt,          DSTP114
      & TMAM,TMIM,TAVM,bvf,den0,tfac,zt,als0,INTENS,iu0,CF,deltaZF,      DSTP115
      & deltaTF,deltaTEX,TINF,TF)                                         DSTP115a
C... Area average height                                              DSTP116
*****

```

The coefficient on the viscosity term for the wind calculations is changed to 0.04 (from 1.0).

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      VISC = BETA*TEMP**1.5/(TEMP + SVAL)                                DSTP133
      VISCFAC = VISC/(1.0E6*DENS*VLL**2)                                DSTP134
C... FUG, FVG = Coriolis parameter times components of areostrophic    DSTP135
***** Mars-GRAM 3.4\MARSSUBS.FOR
      VISC = BETA*TEMP**1.5/(TEMP + SVAL)                                DSTP133
C... Use multiplier to scale wind magnitude                             DSTP134
      VISCFAC = 0.04*VISC/(1.0E6*DENS*VLL**2)                           DSTP134a
C... FUG, FVG = Coriolis parameter times components of areostrophic    DSTP135
*****

```

The allowable upper and lower limits on the density perturbations are adjusted to better account for the stability limits that would be encountered.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      IF(RHO.GE.0.0)DENSP = DENS*(1. + wave) + RHO*DPLUS                DSTP237
      If (DENSP .lt. 0.0)DENSP = 0.05*DENS                               DSTP238
C... Standard deviation in random density perturbation (% of mean),     DSTP239
***** Mars-GRAM 3.4\MARSSUBS.FOR
      IF(RHO.GE.0.0)DENSP = DENS*(1. + wave) + RHO*DPLUS                DSTP237
C... Re-check upper and lower bounds on density perturbations           DSTP237a
      If (DENSP .lt. 0.05*DENS)DENSP = 0.05*DENS                       DSTP238
      If (DENSP .gt. (1.+pertmax)*DENS)DENSP = (1.+pertmax)*DENS        DSTP238a
C... Standard deviation in random density perturbation (% of mean),     DSTP239
*****

```

A re-check of the density perturbation values is done, by comparing with the stability limits.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      SIGD = 50.*(DENSHI-DENSLO)/DENS                                    DSTP241
C... Add Zurek wave amplitudes to DENSHI, subtract from DENSLO          DSTP242
***** Mars-GRAM 3.4\MARSSUBS.FOR
      SIGD = 50.*(DENSHI-DENSLO)/DENS                                    DSTP241
C... Re-check SIGD, DENSHI and DENSLO                                    DSTP241a
      If (SIGD.gt.100.*pertmax)Then                                     DSTP241b
          SIGD = 100.*pertmax                                           DSTP241c
          DENSHI = DENS*(1. + pertmax)                                   DSTP241d
          DENSLO = DENS/(1. + pertmax)                                   DSTP241e
      Endif                                                             DSTP241f
C... Add Zurek wave amplitudes to DENSHI, subtract from DENSLO          DSTP242
*****

```

The Mars orbital radius (MARSAU) and the solar longitude (SUNLON) are added to the output for the LIST file.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      If(iup.gt.0)Write(iup,590)CSEC,CSEC/onesol,ALS,OHGT,OHGTS,        DSTP248

```

```

      & HSCALE,CLAT,CLON,SUNLON,TLOCAL
590 FORMAT(' Time (rel. to T0) =',F10.1,' sec. (' ,F8.3,' sols) ',
***** Mars-GRAM 3.4\MARSSUBS.FOR
      If(iup.gt.0)Write(iup,590)CSEC,CSEC/onesol,ALS,OHGT,OHGTS,
      & HSCALE,CLAT,CLON,SUNLAT,MARSAU,SUNLON,TLOCAL
590 FORMAT(' Time (rel. to T0) =',F10.1,' sec. (' ,F8.3,' sols) ',
*****

```

The formats are revised to accommodate the new output values. The line numbers are changed on several lines to allow for these changes.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      & 'Scale Height = ',F6.2,' km/' Latitude = ',F8.3,' degrees ',
      & ' West Longitude = ',F8.3,' degrees/' Sun Longitude = ',
      & F8.3,' deg. Local Time = ',F6.2,' Mars hours')
      Call cospar(OHGT,tcos,pcos,dcos)
      If (dcos.le.0.0)Then
        devlo = -99.9
        devav = -99.9
        devhi = -99.9
      Else
        devlo = 100.*(DENSLO-dcos)/dcos
        devav = 100.*(DENS-dcos)/dcos
        devhi = 100.*(DENSXI-dcos)/dcos
      Endif
      If(iup.gt.0)Write(iup,600)TEMP,PRES,DENSLO,DENS,DENSXI,
***** Mars-GRAM 3.4\MARSSUBS.FOR
      & 'Scale Height = ',F6.2,' km/' Latitude = ',F8.3,' degrees ',
      & ' West Longitude = ',F8.3,' degrees/' Sun Latitude =',F9.2,
      & ' deg. Mars Orbital Radius =',F6.3,' AU/' Sun Longitude ='
      & ,F8.2,' deg. Local Time = ',F6.2,' Mars hours')
      If (iup.gt.0.and.OHGT.gt.75.0) Write(iup,595)Texos,Tbase,Zbase
595 Format(' Exospheric Temp. = ',F6.1,' K',7X,'Tbase = ',F6.1,
      & ' K',3X,' Zbase = ',F6.1,' km')
      Call cospar(OHGT,tcos,pcos,dcos)
      If (dcos.le.0.0)Then
        devlo = -99.9
        devav = -99.9
        devhi = -99.9
      Else
        devlo = 100.*(DENSLO-dcos)/dcos
        devav = 100.*(DENS-dcos)/dcos
        devhi = 100.*(DENSXI-dcos)/dcos
      Endif
      If(iup.gt.0)Write(iup,600)TEMP,PRES,DENSLO,DENS,DENSXI,
*****

```

The output variable for NVARX=8 is changed to local solar time in hours (from hour angle in degrees).

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      If(NVARX.EQ.7)VARX = ALS
      If(NVARX.EQ.8)VARX = TLOCAL*15.
      Alogdens = 0.0
***** Mars-GRAM 3.4\MARSSUBS.FOR
      If(NVARX.EQ.7)VARX = ALS
      If(NVARX.EQ.8)VARX = TLOCAL
      Alogdens = 0.0
*****

```

The output variable for NVMRY=8 is changed to local solar time in hours (from hour angle in degrees).

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      If(NVARY.EQ.7)VARY = ALS                      DSTP324
      If(NVARY.EQ.8)VARY = TLOCAL*15.                DSTP325
      WRITE(21,795)VARX,VARY,SIGD                    DSTP326
***** Mars-GRAM 3.4\MARSSUBS.FOR
      If(NVARY.EQ.7)VARY = ALS                      DSTP324
      If(NVARY.EQ.8)VARY = TLOCAL                    DSTP325
      WRITE(21,795)VARX,VARY,SIGD                    DSTP326
*****

```

The new coefficients are loaded for the 687 day plus 777 day sun longitude calculations (previously a single, 696 day, periodicity was assumed).

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
C... d0-d6 = Fourier coefficients for lonsun calculation      ORBT 12a
      data d0,d1,d2,d3,d4,d5,d6/-3.5158255d0,6.5240771d0,-9.3284323d0, ORBT 13
      & 1.9052424d0,2.4887938d0,-0.49182825d0,0.10130513d-1/ ORBT 14
C... per1 = 687 day period; per2 = 696 day period            ORBT 14a
      per1=6.87d2/TWOPI                                       ORBT 15
      per2=6.96d2/TWOPI                                       ORBT 16
      PI180 = TWOPI/3.60d2                                     ORBT 17
***** Mars-GRAM 3.4\MARSSUBS.FOR
C... d0-d6 = Fourier coefficients for lonsun calculation      ORBT 12a
      Data e0,e1,e2,e3,e4,e5,e6/- .61024174D-01,1.8014752D0,.35080142D0, ORBT 12b
      & .11820528D0,-.23869660D0,-.56879633D-01,-.42787450D-01/ ORBT 12c
      Data d0,d1,d2,d3,d4,d5,d6/-3.4766116D0,10.199478D0,2.7450878D0, ORBT 13
      & -3.2726522D0,-.67435053D-01,.52016400D0,.11903292D0/ ORBT 13a
C... per1 = 687 day period; per2 = 777 day period            ORBT 14
      per1=6.87d2/TWOPI                                       ORBT 15
      per2=7.77d2/TWOPI                                       ORBT 16
      PI180 = TWOPI/3.60d2                                     ORBT 17
*****

```

The comment line is modified and the computation of the time variable TIME2 is moved.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      xlon = lon0 + 3.60d2*(date - 2.922d3)/perlon          ORBT 20
C... TIME1, TIME2 = time variables for periods PER1 and PER2 ORBT 20a
      TIME1=DATE/PER1                                         ORBT 21
      TIME2=DATE/PER2                                         ORBT 22
C... Lsubs calculation (REAL*8)                               ORBT 22a
***** Mars-GRAM 3.4\MARSSUBS.FOR
      xlon = lon0 + 3.60d2*(date - 2.922d3)/perlon          ORBT 20
C... TIME1 = time variable for period PER1                    ORBT 20a
      TIME1=DATE/PER1                                         ORBT 21
C... Lsubs calculation (REAL*8)                               ORBT 22a
*****

```

The new, dual period, solar longitude model equations are evaluated.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
C... lonsun calculation (REAL*8)                               ORBT 27a
      LON=D0+D1*DSIN(TIME2)+D2*DCOS(TIME2)+D3*DSIN(2.0d0*TIME2) ORBT 28
      & +d4*DCOS(2.0d0*time2)+d5*DSIN(3.0d0*time2)+d6*DCOS(3.0d0*time2) ORBT 29
      & +xlon                                                  ORBT 30
C... Put Lsubs and lonsun into 0-360 degree range             ORBT 30a
      LS = DMOD(LS,3.6D2)                                       ORBT 31
***** Mars-GRAM 3.4\MARSSUBS.FOR
C... lonsun calculation (REAL*8)                               ORBT 27a
      time = (date-2.921d3)/per1                                ORBT 27b
      time2 = (date-2.921d3)/per2                              ORBT 27c
      xlon=D0+D1*DSIN(TIME)+D2*DCOS(TIME)+D3*DSIN(2.0d0*TIME) ORBT 28
      & +d4*DCOS(2.0d0*time)+d5*DSIN(3.0d0*time)+d6*DCOS(3.0d0*time) ORBT 29
      & + xlon                                                  ORBT 30
      LON=E0+E1*DSIN(time2)+E2*DCOS(time2)+E3*DSIN(2.0d0*time2) ORBT 30a

```

```

      & +E4*DCOS(2.0d0*time2)+E5*DSIN(3.0d0*time2)+E6*DCOS(3.0d0*time2) ORBT 30b
      & + xlon ORBT 30c
C... Put Lsubs and lonsun into 0-360 degree range ORBT 30d
      LS = DMOD(LS,3.6D2) ORBT 31
*****

```

The new variables (sunlat, deltaZF, deltaTF, deltaTEX, TINF, and TF) are added to the argument list for the call to subroutine Stewart2.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      SUBROUTINE STEWART2 ( RAUI, LSUN, LAT, LST, TOTALPRZ, TZ, STW2 1
      & TOTALMDZ, CHGT, RSTAR, H, MOLWTG, SIGMA, als0, INTENS, iu0) STW2 2
C STW2 3
***** Mars-GRAM 3.4\MARSSUBS.FOR
      SUBROUTINE STEWART2 ( RAUI, LSUN, LAT, LST, TOTALPRZ, TZ, STW2 1
      & TOTALMDZ, CHGT, RSTAR, H, MOLWTG, SIGMA, als0, INTENS, iu0, STW2 2
      & sunlat,deltaZF,deltaTF,deltaTEX,TINF,TF) STW2 2a
C STW2 3
*****

```

A comment line is added to clarify that FBARR is for the Mars orbital position.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      RAU = RAUI STW2 28
      FBARR = FBAR / (RAU**2) STW2 29
***** Mars-GRAM 3.4\MARSSUBS.FOR
      RAU = RAUI STW2 28
C... Convert solar 10.7 cm flux to Mars position STW2 28a
      FBARR = FBAR / (RAU**2) STW2 29
*****

```

The local values of the thermospheric parameters are evaluated by calling the new subroutine Thermpar.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      CALL PRSEAS(LSUN, LAT, PFAC) STW2 31
      if(FLAG.gt.0)Write(iu0,*)' RREF, RAU, GZ = ',RREF,RAU,GZ STW2 32
***** Mars-GRAM 3.4\MARSSUBS.FOR
      CALL PRSEAS(LSUN, LAT, PFAC) STW2 31
C... Evaluate the basic parameters for the thermosphere model STW2 31a
      Call Thermpar(RAU,FBARR,LAT,LST,SUNLAT,TINF0,TF0,ZF0,SCALE) STW2 31b
      if(FLAG.gt.0)Write(iu0,*)' RREF, RAU, GZ = ',RREF,RAU,GZ STW2 32
*****

```

The modifications, for the Stewart adjustments (ES), pressure (DR), dust, and the new adjustment parameter deltaZF, are added to the value (ZF0) computed by Thermpar.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      DUST = DUST * EXP(ES(10)) STW2 37
      ZF = (124.4 * SMA / RAU) * EXP(ES(8) + ES(9)) + DR + DUST STW2 38
      ZZF = CHGT - ZF STW2 39
***** Mars-GRAM 3.4\MARSSUBS.FOR
      DUST = DUST * EXP(ES(10)) STW2 37
C... Height of base of thermosphere STW2 37a
      ZF = ZF0 * EXP(ES(8) + ES(9)) + DR + DUST + deltaZF STW2 38
C... Height above base of thermosphere STW2 38a
      ZZF = CHGT - ZF STW2 39
*****

```

The modifications, for the Stewart adjustments (ES) and the new adjustment parameter deltaTEX, are added to the value (TINF0) computed by Thermpar.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      RF = RREF + ZF                                STW2 45
      TINF = 4.11 * (11.0 + FBARR) * EXP(ES(2) + ES(3)) STW2 46
      TF = (170.0 * SMA / RAU) * EXP(ES(8) + ES(9)) STW2 47
      If (FLAG .GT. 0) then                          STW2 48
***** Mars-GRAM 3.4\MARSSUBS.FOR
      RF = RREF + ZF                                STW2 45
C... Exospheric temperature                         STW2 45a
      TINF = TINF0 * EXP(ES(2) + ES(3)) + deltaTEX STW2 46
C... Temperature at base of thermosphere            STW2 46h
      TF = TF0 * EXP(ES(8) + ES(9)) + deltaTF      STW2 47
      If (FLAG .GT. 0) then                          STW2 48
*****

```

The SCALE parameter is added as an argument for the THERMOS subroutine.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      CALL THERMOS(FLAG, ES, TINF, TF, LAT, LST, ZF, RF, ZZF, TOTALPRZ, STW2 58
& TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ, iu0) STW2 59
C... SCALE HEIGHT, km                               STW2 60
***** Mars-GRAM 3.4\MARSSUBS.FOR
      CALL THERMOS(FLAG, ES, TINF, TF, LAT, LST, ZF, RF, ZZF, TOTALPRZ, STW2 58
& TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ, iu0, SCALE) STW2 59
C... SCALE HEIGHT, km                               STW2 60
*****

```

The SCALE parameter is added as an argument is the call statemnt for the THERMOS subroutine.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
      SUBROUTINE THERMOS (FLAG, ES, TINF, TF, LAT, LST, ZF, RF, ZZF, THRM 1
& TOTALPRZ, TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ, iu0) THRM 2
      INTEGER FLAG, iu0                                     THRM 3
      DIMENSION ES(0:11), PRZ(0:11), NDZ(0:11), MDZ(0:11) THRM 4
***** Mars-GRAM 3.4\MARSSUBS.FOR
      SUBROUTINE THERMOS (FLAG, ES, TINF, TF, LAT, LST, ZF, RF, ZZF, THRM 1
& TOTALPRZ, TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ, iu0, THRM 2
& SCALE)                                                  THRM 2a
      INTEGER FLAG, iu0                                     THRM 3
      DIMENSION ES(0:11), PRZ(0:11), NDZ(0:11), MDZ(0:11) THRM 4
*****

```

Computation of the SCALE parameter within the THERMOS subroutine is deleted, since its value now is input via the argument list.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
C... FO = PARAMETER IN EQUATION FOR ATOMIC OXYGEN CONTENT I THRM 39
      SCALE = TF / 9.20                                     THRM 40
      M(0) = 44.011                                         THRM 41
***** Mars-GRAM 3.4\MARSSUBS.FOR
C... FO = PARAMETER IN EQUATION FOR ATOMIC OXYGEN CONTENT I THRM 39
      M(0) = 44.011                                         THRM 41
*****

```

The climate adjustment factors (CF) are added to the argument list for the subroutine TEMPS.

```

***** Mars-GRAM 3.34\MARSSUBS.FOR
C-----THRM143
      Subroutine Temps(T0bar, Tsurf, gam, alat, dlon, dustM, dustA, als, T) TMPS 1
C                                             TMPS 2
***** Mars-GRAM 3.4\MARSSUBS.FOR
C-----THRM143
      Subroutine Temps(T0bar, Tsurf, gam, alat, dlon, dustM, dustA, als, T, CF) TMPS 1

```


C
***** TMPS 2

The climate adjustment factors (CF) are added to the dimension statement for the subroutine TEMPS.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      Dimension gam(5),T(0:5),dz(5),z(5),factor(5),dfactor(5),afact(5)  TMPS 17
      & ,A25(0:6),B25(0:6),C25(0:6)                                     TMPS 18
C... Coefficients for T(25 km) correction to gammas                    TMPS 19
***** Mars-GRAM 3.4\MARSSUBS.FOR
      Dimension gam(5),T(0:5),dz(5),z(5),factor(5),dfactor(5),afact(5)  TMPS 17
      & ,A25(0:6),B25(0:6),C25(0:6),CF(0:5)                             TMPS 18
C... Coefficients for T(25 km) correction to gammas                    TMPS 19
*****
```

The temperature at the significant levels are evaluated, with the inclusion of a multiplicative climate adjustment factor (CF).

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
      T(0) = Tsurf                                                    TMPS138
C... Re-evaluate lapse rates (deg./km), based on actual temperatures  TMPS139
***** Mars-GRAM 3.4\MARSSUBS.FOR
      T(0) = Tsurf                                                    TMPS138
C... Apply climate adjustment factors                                  TMPS138a
      Do 45 i = 0,5                                                    TMPS138b
      T(i) = T(i)*CF(i)                                                TMPS138c
      45 Continue                                                       TMPS138d
C... Re-evaluate lapse rates (deg./km), based on actual temperatures  TMPS139
*****
```

The new subroutine Thermpar is added. Thermpar evaluates the local values of TINF0, the exospheric temperature (K), TF0, the temperature (K) at the base of the thermosphere, ZF0, the height (km) of the base of the thermosphere, and SCALE, the scale height (km) for the thermospheric temperature variations.

```
***** Mars-GRAM 3.34\MARSSUBS.FOR
C-----TMPS144
      Subroutine Tsurface(sitla,sitlo,sunla,sunlo,als,au,Tsurf,        TSRF 1
***** Mars-GRAM 3.4\MARSSUBS.FOR
C-----TMPS144
      Subroutine Thermpar(RAU,FBARR,lat,LST,sunlat,TINF0,TF0,ZF0,      TPAR 1
      & SCALE)                                                           TPAR 2
      REAL lat,LST,LATMAX                                               TPAR 3
      Data LATMAX/25.4/                                                 TPAR 4
C                                                                           TPAR 5
C.....TPAR 6
C                                                                           TPAR 7
C... Thermospheric parameters, revised from the original Stewart      TPAR 8
C parameterizations:                                                    TPAR 9
C SMA = 1.523691                                                         TPAR 10
C ZF0 = 124.4 * (SMA/RAU)                                                TPAR 11
C TINF0 = 4.11 * (11.0 + FBARR)                                          TPAR 12
C TF0 = 170.0 * (SMA/RAU)                                                TPAR 13
C SCALE = TF0 / 9.20                                                     TPAR 14
C                                                                           TPAR 15
C The new parameterizations are based on four data sets from the      TPAR 16
C University of Arizona Mars Thermospheric Global Circulation          TPAR 17
C Model (MTGCM), cases MGS97L, MGS98L, MANC00, and MGS97E. For        TPAR 18
C a description of the MTGCM model and its output, see Bougher,        TPAR 19
C et al., Journal of Geophysical Research, vol. 95 (B9), pp.          TPAR 20
C 14,811 - 14,827, August 30, 1990.                                    TPAR 21
C                                                                           TPAR 22
C.....TPAR 23
C                                                                           TPAR 24
```

```

C      Inputs:
C      RAU      = orbital position radius (AU)
C      FBARR     = 10.7 cm solar flux at Mars position
C      lat      = latitude for evaluation of parameters (degrees)
C      LST      = local solar time (Mars hours) at evaluation point
C      sunlat   = latitude of sun (degrees)
C      Outputs:
C      TINF0    = Exospheric temperature (K)
C      TF0      = Temperature at base of thermosphere (K)
C      ZF0      = Height of base of thermosphere (km)
C      SCALE    = Scale height for temperature variations (km)
C
C      Output values are un-corrected for Stewart (ES array) variations,
C      pressure and dust effects. These factors are accounted for in
C      the Stewart2 subroutine. Adjustment factors deltaTEX, deltaTF
C      and deltaZF are also added after computation of these values.
C.....
C
C... Degrees to radians conversion factor
C      pil80 = Atan(1.)/45.
C... Global mean exospheric temperature (K) versus 10.7 cm flux
C      Tbar = 156.3 + 0.9427*FBARR
C... Zonal average exospheric temperature (K) versus latitude
C      Tavg = Tbar*(1. + 1.369E-4*sunlat*lat)
C... Phase angles (hours) for local solar time variation
C      t1 = 13.2 - 0.00119*sunlat*lat
C      t2 = 9.4 - 0.00231*sunlat*lat
C... Amplitude factor for local solar time variation
C      cphi = Cos(pil80*(lat + sunlat)/(1. + LATMAX/90.))
C... Exospheric temperature (K) versus local solar time
C      TINF0 = Tavg*(1. + 0.22*cphi*Cos(pil80*15.0*(LST-t1)) +
C      & 0.04*cphi*Cos(pil80*30.0*(LST-t2)))
C... Global mean height of thermosphere base (km)
C      Zbar = 197.94 - 49.058*RAU
C... Latitude variation factor
C      factlat = (sunlat/LATMAX)*(lat/77.5)**3
C... Zonal average base height (km) versus latitude
C      Zavg = Zbar + 4.3*factlat
C... Amplitudes for local solar time variation
C      A1 = 1.5 - Cos(pil80*4.0*lat)
C      A2 = 2.3*(Cos(pil80*(lat + 0.5*sunlat))**3
C... Phase angles (hours) for local solar time variation
C      t1 = 16.2 - (sunlat/LATMAX)*Atan(pil80*10.0*lat)
C      t2 = 11.5
C... Base height of thermosphere (km) versus local solar time
C      ZF0 = Zavg + A1*Cos(pil80*15.0*(LST-t1)) +
C      & A2*Cos(pil80*30.0*(LST-t2))
C... Global mean temperature (K) at thermosphere base, versus FBARR
C      Tbar = 113.7 + 0.5791*FBARR
C... Zonal average temperature at thermosphere base (K) vs. latitude
C      Tavg = Tbar*(1. + 0.186*factlat)
C... Amplitudes for local solar time variation
C      A1 = 0.06 - 0.05*Cos(pil80*4.0*lat)
C      A2 = 0.1*(Cos(pil80*(lat + 0.5*sunlat))**3
C... Phase angles (hours) for local solar time variation
C      t1 = 17.5 - 2.5*(sunlat/LATMAX)*Atan(pil80*10.0*lat)
C      t2 = 10.0 + 2.0*(lat/77.5)**2
C... Thermosphere base temperature (K) versus local solar time
C      TF0 = Tavg*(1.0 + A1*Cos(pil80*15.0*(LST-t1)) +
C      & A2*Cos(pil80*30.0*(LST-t2)))
C... Global mean scale height (km) of thermospheric temperature
C      SCALE = 8.38 + 0.09725*FBARR
C... Zonal average temperature scale height (km) vs. latitude
C      SCALE = SCALE*(1.14 - 0.18*Cos(pil80*lat))
C      Return
C      End
C-----

```

```

TPAR 25
TPAR 26
TPAR 27
TPAR 28
TPAR 29
TPAR 30
TPAR 31
TPAR 32
TPAR 33
TPAR 34
TPAR 35
TPAR 36
TPAR 37
TPAR 38
TPAR 39
TPAR 40
TPAR 41
TPAR 42
TPAR 43
TPAR 44
TPAR 45
TPAR 46
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TPAR 74
TPAR 75
TPAR 76
TPAR 77
TPAR 78
TPAR 79
TPAR 80
TPAR 81
TPAR 82
TPAR 83
TPAR 84
TPAR 85
TPAR 86
TPAR 87
TPAR 88
TPAR 89
TPAR 90
TPAR 91

```

```

Subroutine Tsurface(sitla,sitlo,sunla,sunlo,als,au,Tsurf,      TSRF  1
*****

```

4. Comparing SETUP.FOR for Mars-GRAM 3.34 and Mars-GRAM 3.4

The official version number is changed.

```

***** Mars-GRAM 3.34\SETUP.FOR
C
1 Format(' Mars-GRAM Batch version 3.34 - November 1, 1995')      SETU  3
C
1 Format(' Mars-GRAM Batch version 3.34 - November 1, 1995')      SETU  4
C
***** Mars-GRAM 3.4\SETUP.FOR
C
1 Format(' Mars-GRAM Batch version 3.4 - April 1, 1996')          SETU  3
C
1 Format(' Mars-GRAM Batch version 3.4 - April 1, 1996')          SETU  4
C
1 Format(' Mars-GRAM Batch version 3.4 - April 1, 1996')          SETU  5
*****

```

The climate adjustment factors (CF) and the thermospheric adjustment parameters (DZF = deltaZF, dTF = deltaTF, and dTEX = deltaTEX) are added to the common DATACOM.

```

***** Mars-GRAM 3.34\SETUP.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,      SETU 19
& intens,iu0,iup,maxfiles                                          SETU 20
C.....                                                            SETU 21
***** Mars-GRAM 3.4\SETUP.FOR
& logscale,dustlat,dustlon,dusthgt,radmax,Rref,modpert,als0,      SETU 19
& intens,iu0,iup,maxfiles,CF(0:5),dZF,dTF,dTEX                    SETU 20
C.....                                                            SETU 21
*****

```

Default values are established for all of the input parameters. The default values are those that are applicable to the Viking 1 lander site date and time, at the Viking 1 lander surface position. With the default values set, only those parameters that differ from their default values need to be input in the NAMELIST file.

```

***** Mars-GRAM 3.34\SETUP.FOR
DATA IDAY/0,31,59,90,120,151,181,212,243,273,304,334/          SETU 42
C.....                                                            SETU 43
***** Mars-GRAM 3.4\SETUP.FOR
DATA IDAY/0,31,59,90,120,151,181,212,243,273,304,334/          SETU 42
C... Establish default values for input parameters               SETU 42a
Data LSTFL,OUTFL/'LIST','OUTPUT'/                                SETU 42b
C... Default time = Viking 1 Lander                               SETU 42c
Data Month,Mday,Myyear,Ihr,Imin,Sec/7,20,76,12,30,0.0/          SETU 42d
C... Default Solar Flux parameters                               SETU 42e
Data F107,Std1/68.,0.0/                                          SETU 42f
C... Default position = Viking 1 Lander Site, height = 0         SETU 42g
Data Flat,Flon,Fhgt,Delhgt,Dellat,Dellon,Delttime/22.,48.,-0.5, SETU 42h
& 10.,3*0./                                                      SETU 42i
C... CF climate factors default to 1.0                           SETU 42j
Data CF0,CF5,CF15,CF30,CF50,CF75/6*1.0/                         SETU 42k
C... Terms deltaZF, deltaTF and deltaTEX default to 0.0          SETU 42l
Data deltaZF,deltaTF,deltaTEX/3*0.0/                             SETU 42m
C... Default random number seed                                  SETU 42n
Data NR1/1001/                                                    SETU 42o
C.....                                                            SETU 43
*****

```

The climate adjustment factors (CF) and the thermospheric adjustment parameters (deltaZF, deltaTF, and deltaTEX) are added to the NAMELIST definition.

```

***** Mars-GRAM 3.34\SETUP.FOR
      & NVARX,NVARY,LOGSCALE,FLAT,FLON,FHGT,DELHGT,DELLAT,DELLON,
      & DELTIME
C.....
***** Mars-GRAM 3.4\SETUP.FOR
      & NVARX,NVARY,LOGSCALE,FLAT,FLON,FHGT,DELHGT,DELLAT,DELLON,
      & DELTIME,CF0,CF5,CF15,CF30,CF50,CF75,deltaZF,deltaTF,deltaTEX
C.....
*****

```

The climate adjustment factors and thermospheric adjustment parameters are loaded into the common DATACOM.

```

***** Mars-GRAM 3.34\SETUP.FOR
      Read(8,INPUT)
C.....
***** Mars-GRAM 3.4\SETUP.FOR
      Read(8,INPUT)
      CF(0) = CF0
      CF(1) = CF5
      CF(2) = CF15
      CF(3) = CF30
      CF(4) = CF50
      CF(5) = CF75
      Do 5 i = 0,5
        If (CF(i).le.0.0)Stop ' Bad CF value'
5      Continue
      dzF = deltaZF
      dTF = deltaTF
      dTEX = deltaTEX
C.....
*****

```

Appendix B - Reference LIST Output for Mars-GRAM 3.4

Mars-GRAM Batch version 3.4 - April 1, 1996

```

Date = 7/20/1976 Julian Date = 2442980.0 GMT Time = 12:30: .0
F10.7 flux = 68.0 (1 AU) 25.0 (Mars), standard deviation = .0
Perturbation model = 3 Starting random number = 1001
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = -.50 km ( .00 km) Scale Height = 12.50 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Temperature = 243.8 K Pressure = 7.479E+02 N/m**2
Density (Low, Avg., High) = 1.500E-02 1.604E-02 1.709E-02 kg/m**3
Departure, COSPAR NH Mean = -7.6 % -1.2 % 5.3 %
Density perturbation = 5.72 % of mean value
Eastward Wind = 4.3 m/s Northward Wind = -.4 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 9.50 km ( 10.00 km) Scale Height = 10.40 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Temperature = 202.9 K Pressure = 3.058E+02 N/m**2
Density (Low, Avg., High) = 7.621E-03 7.886E-03 8.154E-03 kg/m**3
Departure, COSPAR NH Mean = 12.9 % 16.8 % 20.8 %
Density perturbation = -1.39 % of mean value
Eastward Wind = 1.4 m/s Northward Wind = -5.3 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 19.50 km ( 20.00 km) Scale Height = 9.50 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Temperature = 185.2 K Pressure = 1.124E+02 N/m**2
Density (Low, Avg., High) = 3.041E-03 3.175E-03 3.312E-03 kg/m**3
Departure, COSPAR NH Mean = 10.3 % 15.1 % 20.1 %
Density perturbation = -1.42 % of mean value
Eastward Wind = -1.7 m/s Northward Wind = -8.7 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 29.50 km ( 30.00 km) Scale Height = 8.73 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Temperature = 170.4 K Pressure = 3.812E+01 N/m**2
Density (Low, Avg., High) = 1.098E-03 1.170E-03 1.244E-03 kg/m**3
Departure, COSPAR NH Mean = 6.2 % 13.2 % 20.3 %
Density perturbation = -.33 % of mean value
Eastward Wind = -4.6 m/s Northward Wind = -13.5 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 39.50 km ( 40.00 km) Scale Height = 8.20 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Temperature = 160.0 K Pressure = 1.198E+01 N/m**2
Density (Low, Avg., High) = 3.667E-04 3.915E-04 4.173E-04 kg/m**3
Departure, COSPAR NH Mean = 2.1 % 9.1 % 16.2 %
Density perturbation = -.34 % of mean value
Eastward Wind = -8.0 m/s Northward Wind = -19.7 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 49.50 km ( 50.00 km) Scale Height = 7.68 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU

```

Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Temperature = 149.8 K	Pressure = 3.511E+00 N/m**2
Density (Low, Avg., High) =	1.108E-04 1.226E-04 1.347E-04 kg/m**3
Departure, COSPAR NH Mean =	-3.5 % 6.8 % 17.3 %
Density perturbation =	5.25 % of mean value
Eastward Wind = -11.7 m/s	Northward Wind = -26.4 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 59.50 km (60.00 km)	Scale Height = 7.40 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Temperature = 144.3 K	Pressure = 9.703E-01 N/m**2
Density (Low, Avg., High) =	3.040E-05 3.517E-05 4.002E-05 kg/m**3
Departure, COSPAR NH Mean =	-10.3 % 3.8 % 18.1 %
Density perturbation =	-8.82 % of mean value
Eastward Wind = -15.9 m/s	Northward Wind = -33.7 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 69.50 km (70.00 km)	Scale Height = 7.14 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Temperature = 139.2 K	Pressure = 2.579E-01 N/m**2
Density (Low, Avg., High) =	8.376E-06 9.690E-06 1.103E-05 kg/m**3
Departure, COSPAR NH Mean =	-10.2 % 3.9 % 18.2 %
Density perturbation =	-2.23 % of mean value
Eastward Wind = -20.4 m/s	Northward Wind = -39.8 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 79.50 km (80.00 km)	Scale Height = 7.25 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 134.9 K	Pressure = 6.050E-02 N/m**2
Density (Low, Avg., High) =	1.838E-06 2.343E-06 2.892E-06 kg/m**3
Departure, COSPAR NH Mean =	-24.9 % -4.3 % 18.1 %
Density perturbation =	3.56 % of mean value
Eastward Wind = -25.4 m/s	Northward Wind = -43.8 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 89.50 km (90.00 km)	Scale Height = 7.16 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 132.1 K	Pressure = 1.182E-02 N/m**2
Density (Low, Avg., High) =	3.388E-07 4.663E-07 6.134E-07 kg/m**3
Departure, COSPAR NH Mean =	-47.3 % -27.4 % -4.5 %
Density perturbation =	-34.81 % of mean value
Eastward Wind = -38.3 m/s	Northward Wind = -45.7 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 99.50 km (100.00 km)	Scale Height = 7.11 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 129.9 K	Pressure = 2.279E-03 N/m**2
Density (Low, Avg., High) =	6.544E-08 9.113E-08 1.211E-07 kg/m**3
Departure, COSPAR NH Mean =	-61.5 % -46.4 % -28.8 %
Density perturbation =	-9.68 % of mean value
Eastward Wind = -62.1 m/s	Northward Wind = -47.3 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 109.50 km (110.00 km)	Scale Height = 7.11 km

Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 128.9 K	Pressure = 4.402E-04 N/m**2
Density (Low, Avg., High) =	1.269E-08 1.768E-08 2.350E-08 kg/m**3
Departure, COSPAR NH Mean =	-71.3 % -60.0 % -46.8 %
Density perturbation =	24.11 % of mean value
Eastward Wind = -103.2 m/s	Northward Wind = -50.0 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 119.50 km (120.00 km)	Scale Height = 8.09 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 144.9 K	Pressure = 9.240E-05 N/m**2
Density (Low, Avg., High) =	2.358E-09 3.285E-09 4.366E-09 kg/m**3
Departure, COSPAR NH Mean =	-81.4 % -74.1 % -65.5 %
Density perturbation =	-23.70 % of mean value
Eastward Wind = -139.0 m/s	Northward Wind = -49.7 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 129.50 km (130.00 km)	Scale Height = 10.57 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 185.2 K	Pressure = 3.201E-05 N/m**2
Density (Low, Avg., High) =	6.286E-10 8.759E-10 1.164E-09 kg/m**3
Departure, COSPAR NH Mean =	-84.2 % -78.0 % -70.7 %
Density perturbation =	.46 % of mean value
Eastward Wind = -177.2 m/s	Northward Wind = -72.5 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 139.50 km (140.00 km)	Scale Height = 11.78 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 200.9 K	Pressure = 1.313E-05 N/m**2
Density (Low, Avg., High) =	2.325E-10 3.240E-10 4.306E-10 kg/m**3
Departure, COSPAR NH Mean =	-79.8 % -71.8 % -62.5 %
Density perturbation =	7.64 % of mean value
Eastward Wind = -193.9 m/s	Northward Wind = -108.6 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 149.50 km (150.00 km)	Scale Height = 12.59 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 206.9 K	Pressure = 5.780E-06 N/m**2
Density (Low, Avg., High) =	9.633E-11 1.342E-10 1.784E-10 kg/m**3
Departure, COSPAR NH Mean =	-80.4 % -72.7 % -63.7 %
Density perturbation =	24.11 % of mean value
Eastward Wind = -178.4 m/s	Northward Wind = -157.3 m/s

Time (rel. to T0) = .0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 159.50 km (160.00 km)	Scale Height = 13.39 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km
Temperature = 209.3 K	Pressure = 2.674E-06 N/m**2
Density (Low, Avg., High) =	4.217E-11 5.875E-11 7.808E-11 kg/m**3
Departure, COSPAR NH Mean =	-83.2 % -76.6 % -68.9 %

Density perturbation =	-46.41 % of mean value
Eastward Wind = -112.9 m/s	Northward Wind = -191.6 m/s

Time (rel. to T0) =	.0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 169.50 km (170.00 km)	Scale Height = 14.36 km	
Latitude = 22.000 degrees	West Longitude = 48.000 degrees	
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU	
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours	
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km	
Temperature = 210.2 K	Pressure = 1.298E-06 N/m**2	
Density (Low, Avg., High) =	1.919E-11 2.674E-11 3.554E-11 kg/m**3	
Departure, COSPAR NH Mean =	-86.2 % -80.8 % -74.4 %	
Density perturbation =	-14.25 % of mean value	
Eastward Wind = -33.4 m/s	Northward Wind = -168.4 m/s	

Time (rel. to T0) =	.0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 179.50 km (180.00 km)	Scale Height = 15.64 km	
Latitude = 22.000 degrees	West Longitude = 48.000 degrees	
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU	
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours	
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km	
Temperature = 210.6 K	Pressure = 6.652E-07 N/m**2	
Density (Low, Avg., High) =	9.081E-12 1.265E-11 1.682E-11 kg/m**3	
Departure, COSPAR NH Mean =	-88.8 % -84.4 % -79.3 %	
Density perturbation =	-.62 % of mean value	
Eastward Wind = 6.0 m/s	Northward Wind = -116.9 m/s	

Time (rel. to T0) =	.0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 189.50 km (190.00 km)	Scale Height = 17.30 km	
Latitude = 22.000 degrees	West Longitude = 48.000 degrees	
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU	
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours	
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km	
Temperature = 210.8 K	Pressure = 3.617E-07 N/m**2	
Density (Low, Avg., High) =	4.489E-12 6.254E-12 8.312E-12 kg/m**3	
Departure, COSPAR NH Mean =	-90.8 % -87.1 % -82.9 %	
Density perturbation =	.27 % of mean value	
Eastward Wind = 15.7 m/s	Northward Wind = -77.2 m/s	

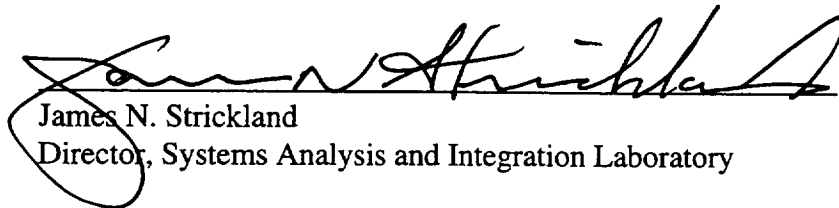
Time (rel. to T0) =	.0 sec. (.000 sols)	Ls = 97.0 deg.
Height = 199.50 km (200.00 km)	Scale Height = 19.35 km	
Latitude = 22.000 degrees	West Longitude = 48.000 degrees	
Sun Latitude = 25.00 deg.	Mars Orbital Radius = 1.649 AU	
Sun Longitude = 108.77 deg.	Local Time = 16.05 Mars hours	
Exospheric Temp. = 210.9 K	Tbase = 128.2 K Zbase = 117.1 km	
Temperature = 210.8 K	Pressure = 2.092E-07 N/m**2	
Density (Low, Avg., High) =	2.334E-12 3.252E-12 4.322E-12 kg/m**3	
Departure, COSPAR NH Mean =	-92.2 % -89.1 % -85.6 %	
Density perturbation =	-8.87 % of mean value	
Eastward Wind = 15.5 m/s	Northward Wind = -52.9 m/s	

APPROVAL

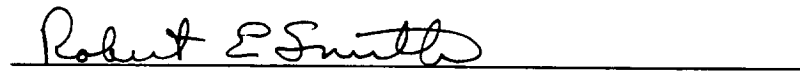
**A REVISED THERMOSPHERE FOR THE MARS GLOBAL REFERENCE
ATMOSPHERIC MODEL (Mars-GRAM VERSION 3.4)**

C. G. Justus, D. L. Johnson and B. F. James

The Information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classifications Officer. This report, in its entirety, has been determined to be unclassified.



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13. ABSTRACT (Maximum 200 words) This report describes the newly-revised model thermosphere for the Mars Global Reference Atmospheric Model (Mars-GRAM, Version 3.4). It also provides descriptions of other changes made to the program since publication of the programmer's guide (Justus et al., 1996) for Mars-GRAM Version 3.34. The original Mars-GRAM model thermosphere was based on the global-mean model of Stewart (1987). The revised thermosphere is based largely on parameterizations derived from output data from the three-dimensional Mars Thermospheric Global Circulation Model (MTGCM) of Bougher et al. (1990). The new thermospheric model includes revised dependence on the 10.7 cm solar flux for the global means of exospheric temperature, temperature of the base of the thermosphere, and scale height for the thermospheric temperature variations, as well as revised dependence on orbital position for global mean height of the base of the thermosphere. Other features of the new thermospheric model are (1) realistic variations of temperature and density with latitude and time of day, (2) more realistic wind magnitudes, based on improved estimates of horizontal pressure gradients, and (3) allowance for user-input adjustments to the model values for mean exospheric temperature and for height and temperature at the base of the thermosphere. Other new features of Mars-GRAM 3.4 include (1) allowance for user-input values of climatic adjustment factors for temperature profiles from the surface to 75 km, and (2) a revised method for computing the sub-solar longitude position in the "ORBIT" subroutine.				
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